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OF THE

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Research · Development · Production · Utilization

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PHILADELPHIA, PENNSYLVANIA

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MONDAY, TUESDAY, WEDNESDAY, THURSDAY AND FRIDAY

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VOLUME FIVE

FOREST PRODUCTS RESEARCH SOCIETY
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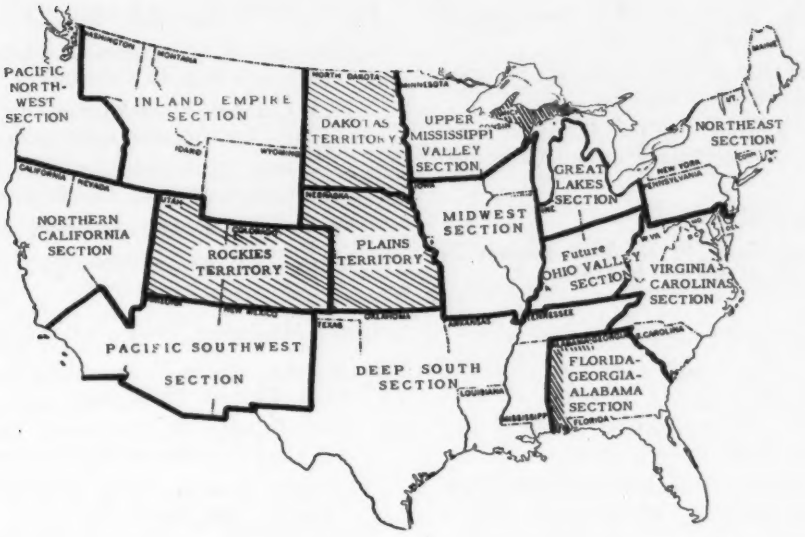

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1951 NATIONAL ANNUAL MEETING

Participating in the Technical Program, besides the Forest Products Research Society, were eight allied organizations—American Paper and Pulp Association, American Society of Mechanical Engineers, American Society for Testing Materials, American Wood-Preservers' Association, Keystone Dry Kiln Club, Northeastern Wood Utilization Council, Society of American Foresters, and Society of the Plastics Industry.

Technical Sessions were held concurrently in the Ballroom, and Room 300 of Convention Hall, Philadelphia. Session I was opened by President Hamilton at 2 p.m., Monday, May 7.

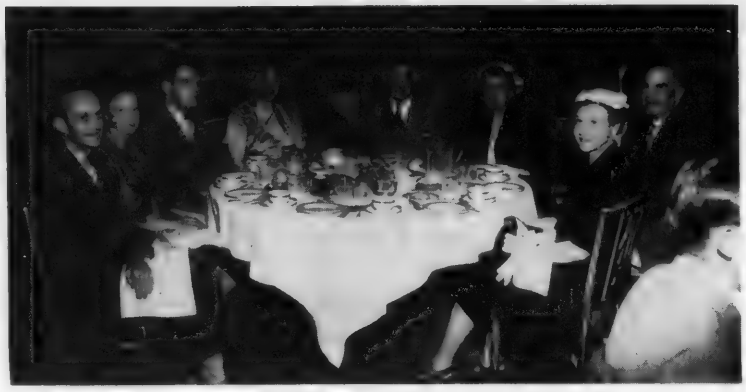
Registration

Registration was opened at 4:00 p.m., Sunday, at the Ben Franklin hotel, resuming at 8:30 a.m., Monday, in Convention Hall. Members of all participating organizations paid a $5.00 registration fee, non-members, $10.00, entitling them also to admission to the industry show, and to a set of preprints of papers to be presented. During the five days a total of 2,313 persons registered for the Industry Show and Technical Sessions. The total combined attendance at ten Sessions was 1,110. The meeting, while attended largely by East Coast people, drew representatives from 44 states, Canada, and foreign countries, including France, Sweden, Germany, Scotland, Israel, Cuba, East Africa, and the Philippines.

General Assembly Luncheon

President Hamilton extended the official welcome of the Society to the registrants and participating organizations, Tuesday, at the official luncheon held in the Center Building, Convention Hall. Special recognition was extended to the members of the

Photos—*top*, a representative group of the more than 50 experts who presented papers at the FPRS 1951 National Meeting; *right*—Convention Hall; general view of registration; new president Roy M. Carter addresses the members; C. Arthur Bruce, past-director, N. P. A. Lumber and Wood Products division.



Left—President Hamilton looks on as President-elect Chesley reports on Constitution; Blake O'Conor; typical group at President's reception and banquet.

1951 Meeting and Show committees for their efforts in behalf of the Society.

J. Alfred Hall, Director of the U. S. Forest Products Laboratory, Madison, Wisconsin, served as toastmaster. Governor John F. Fine, who was unable to be present, sent his greetings through Daniel M. Miller, Deputy Secretary of Forests and Waters, commonwealth of Pennsylvania.

Blake O'Connor, professional staff member of U. S. Senate Select Committee on Small Business, presented the luncheon address, "Problems of Small Business in the Mobilization Program." O'Connor defined small business as plants employing 500 or fewer employes. These comprise 95% of total U. S. plants, and produce 33⅓% of all goods. He offered the assistance of his office to persons unfamiliar with the government procedures in placing business. In describing the immense program of prime and sub-contracts, he stressed the place of more than 5,000 widely scattered U. S. procurement offices in the initial contact of small business.

Field Trips

Tours of inspection through several types of wood industry plants were conducted on Tuesday and Thursday. Trip No. 1 was to the Lester Piano Co., Lester, Pa., to witness modern woodworking machinery and precision techniques in a 75-year-old fine piano manufacturing business.

Trip 2 was to the Ruberoid Company, Gloucester, New Jersey, manufacturers of dry and saturated felts for roofing and flooring. Large quantities of pine and hardwoods are de-fiberized and refined in the process. Trip 3 was a visit to the 100-year-old Henry Disston & Sons, Co., in Philadelphia. The plant occupies 84 buildings covering 70 acres, including steel and rolling mills, tool works and woodworking shops. A trip to Eppinger and Russel, wood-treating plant, was cancelled out.

President's Reception

An informal reception preceded the banquet held in the Crystal Ballroom of the Ben Franklin hotel. Toastmaster George A. Garratt, Dean of the School of Forestry, Yale University, presented outgoing president Hamilton with a handsome set of luggage. After dinner speakers included, David M. Walker, Secretary of the Department of Labor and Industry, Commonwealth of Pennsylvania, and John DaGrosa, State Athletic Commissioner.

FPRS Council Meeting

On Monday evening, May 27, some 28 officers and delegates representing the Sections met with the national Executive Board, for dinner at the Ben Franklin. Discussed were, the Section boundaries, rebate of Section operating funds, membership activity, proposed new Constitution, and Bylaws, and the Society's publications program.

Industry Films

A varied program of some 24 different forest products films was scheduled in the Lecture Room, Commercial Hall. Films were presented daily, from 9:00 a.m. to noon, and 1:00 p.m. to closing. Subjects included, furniture, housing, logging, lumber, millwork, paper, plywood, research, and woodworking.

Executive Board Meetings

The executive boards, both old and new, met at four adjourned sessions, Monday, Wednesday, Thursday and Friday at the Ben Franklin hotel.

Presentation of Papers

In his paper, each author was asked to condense his remarks to a ten-minute summary. This was then followed by discussion from the floor. Thus the complete papers are reproduced, along with discussion and authors' comments, in the fifth Annual Proceedings of the Society.

TECHNICAL SESSION I—Monday, May 7, 1951, 2:00 P. M.

General Subject: Logging and Primary Processing

Co-Sponsor: The Society of American Foresters
Chairman: Fred Dickinson—**Recorder:** Earl Stivers

Truck Transportation of Logs in Southeast Arkansas

DON TUFTS, *Assistant Logging Engineer, Crossett Lumber Company, Crossett, Arkansas, and*
BRUCE METY, *Chief Forester, Southern Lumber Company, Warren, Arkansas*

The current methods of log transportation in Southeast Arkansas are described along with a discussion of the economics involved in truck logging. The costs of two and three ton trucks are compared with those of a six ton truck with emphasis on volumes hauled, distance, and class of road. Cost and performance figures in this report are based on the experience of local operators.

Present Logging Methods

AT THE present time, logs are being hauled by wagons, small trucks, big trucks, railroads, and several combinations of these methods. Animal and tractor drawn wagons are used for short distances where there is a small volume of timber to be moved. Usually, they are used during wet periods to move logs from the woods to roadside areas. These roadside areas act as a storage place for logs, and eventually the logs are loaded on trucks and hauled to the mills as needed.

Most of the logging railroads have disappeared, and those that are left have been inherited from the early days when the virgin forests were cut. The present method of selection cutting and the small size logs will not support railroad operations, and so they have given way to the greater flexibility of improved trucks. Some companies still run railroad trains on track maintained by common carrier railroads, but keep up very little track of their own.

There are many sawmills in the area—varying in size from the portable mill which only cuts 5,000 board feet per day to the large permanent mills that have a daily production in excess of 150,000 board feet. Some of the mills do their own logging while others split up their logging among several contractors.

Most of the logging contractors are small operators. They work on yearly budgets of two to six million board feet, and these low quotas do not provide enough work to warrant large investments in heavy logging equipment. The two-ton truck is the most common size in the woods, although the 2½- and 3-ton trucks are gaining in popularity. These trucks are usually loaded from 20 to 60 percent over the manufacturers' recommended carrying capacities, and supervision of truck drivers is often lacking.

The combined effect of poor supervision and big overloads makes a high repair cost and short life for the small trucks.

The trucks are used on a variety of roads ranging from pavement to woods trails. A high motor speed is maintained most of the time even on good roads, and it is the exceptional engine that isn't replaced within 30,000 miles. One to two years is the normal life of small log trucks.

Ordinarily, the hauling distances vary from one to seventy miles. For the big mills, when the hauling distance is over 20 miles, the small trucks usually unload at a convenient railroad yard. Railroad trains carry the logs the remaining distance to the mill, but this necessitates another handling of the logs. Small mills do not use railroads.

The method of loading logs also limits the size of truck that can be used. Developments of bigger trucks precludes development of faster loading equipment. The standard loader at present is a stiff-boom or A-frame. This type loader is sufficient for small trucks and low volumes of production, but it is too slow and laborious for large trucks. Large trucks have a high fixed cost which goes on whether the trucks are moving or not. A long loading period would add excessive standby costs, but the fast loading swing-boom type of loader is more expensive on a small production quota.

On "hot logging" operations where the logs are moved from the stump to the mill with only a short stop for handling at the loading area, the skidding must keep up with the loading and hauling operations. Delays caused by lack of logs become more costly as larger trucks are used. In other words, large expensive equipment precludes good organization and coordination throughout all phases of the logging operation.

Cost Analysis

The big sawmills in this area are cutting 18 million or more board feet of timber each year. This is sufficient volume to run two or more swing-boom loaders, and thereby realize a fast loading operation. The average round trip hauling distance is 50 miles—with 25 miles being pavement, 20 miles gravel, and 5 miles dirt. Allowing 15 minutes per trip for lost time, the six-ton truck can make four trips per 10-hour day, the three-ton truck 1½ trips, and the two-ton truck 3 trips. The three-ton truck should work a nine-hour day for greatest efficiency. The cost per thousand board feet for the six-ton

truck would be $4.58, for the three-ton truck, $6.02, and for the two-ton truck $6.30. This estimate is for a smooth operation with maximum highway loads. Where the trucks are being constantly weighed by the highway departments, it is best to figure on 94 percent of the maximum payload so that the variation in the weight of the wood will not cause an overload. Also, 20 percent of the calculated cost is added to the estimate to allow for breakdowns and unusual delays.

The total hauling costs per thousand board feet for 90 percent capacity loads and 20 percent added breakdown costs are:

Six-ton truck	$5.85
Three-ton truck	$7.68
Two-ton truck	$8.05

The logging contractors haul an average of four million board feet per year. The average distance of haul is about 30 miles with 10 miles of blacktop, 15 of gravel, and 5 of dirt. The six-ton truck can haul five trips per 10-hour day at $3.32 per thousand board feet, while the three-ton truck would work most economically on a nine-hour day making four trips at a cost of $4.15 per thousand board feet. The two-ton truck cost is $4.19 per thousand board feet, based on four trips per ten-hour day. Again, the payload or cost should be divided by 0.94 to insure staying within legal weight limits, and 20 percent added for breakdown and extra delay costs. (All estimates are based on comparative data found in Table 1 and costs as shown in the machine rates at the end of this report.)

Most of the big sawmills build and maintain roads to extend and fit into the state and county road network. On their own roads there are no weight restrictions, and the trucks may carry capacity loads. The land is relatively flat in this region, and hauling conditions are not severe except on muddy roads. A 25 percent load over the manufacturers' recommended limit is considered economical on logging operations. This extra loading tends to increase the repair and maintenance cost and decrease the speed, but the extra cost is more than offset in the extra payload. At the present time, short radius curves and poor bridge approaches limit the speed of travel on gravel and dirt roads more than the size of the payload. Even with the extra load, the trucks will make approximately the same number of trips per day.

Other savings of private roads over state roads are license fees and highway fuel tax. (In this analysis no fuel tax is computed for dirt roads and half the gravel roads are considered tax free.)

Reworking the first problem for privately owned roads where 45 miles are gravel and 5 miles dirt, we have the following costs per thousand board feet.

Six-ton truck	$4.26
Three-ton truck	$6.80
Two-ton truck	$8.64

The six-ton truck has been figured for a 10-hour day and three trips; the three-ton truck an 11-hour day and three trips; and the two-ton truck an eight-hour day and two trips. The lower hauling costs on private roads are mainly due to the greater payload.

TABLE 1.—PERFORMANCE DATA FOR TRUCKS WITH SEMI-TRAILERS

	Two-ton	Three-ton	Six-ton
Maximum gross combination weight recommended by manufacturers—pounds	28,000	39,000	85,000
Empty truck and trailer weight—pounds	7,700	10,200	27,000
Weight left for payload, pounds	21,300	28,800	58,000
Allowable payload on state roads, pounds	31,000	29,400	46,000
Board feet of logs per load on state roads (up to 25 percent overload)[1]	1,820	2,000	3,150
Board feet of logs per load off state roads (25 percent overload)	1,820	2,460	4,960
Average round trip speed in mph.—pavement	27	35	42
Average round trip speed in mph.—gravel	17	20	24
Average round trip speed in mph.—dirt	12	15	16
Loading time in minutes for legal state load	30	35	30
Loading time in minutes for maximum load	30	40	50

[1]The board feet of logs per load is based on an average weight of 14,600 pounds per thousand board feet of logs.

The total hauling costs per thousand board feet for contractors carrying 94 percent capacity loads with an added 20 percent breakdown cost are:

Six-ton truck	$4.24
Three-ton truck	$5.29
Two-ton truck	5.34

From this analysis, it would appear that the small contractor should also invest in large trucks. However, the insecurity of the contractor's position does not warrant large investments, and the increase in loading cost per thousand board feet for big trucks would offset the savings gained in hauling.

Without the extra work for the loading crew, the contractor needs a minimum work budget of eight million board feet of timber per year to invest in big equipment.

A 20 percent extra cost allowance has been added for breakdowns and unforeseen delays.

For small trucks it is not profitable to build private roads where state and county highways already exist, and for big trucks it is only profitable when large volumes are going to be hauled. The hauling cost per round trip mile for big trucks on company gravel roads is $0.130 per thousand board feet, and on state paved highways $0.155 per thousand board feet. It would take about 40 million board feet of sawlogs and 108 thousand cords of pulpwood to write off the initial investment on a $2,000.00 per mile gravel road. The speed on gravel roads at present is low, but if reasonable care is given to building good bridges and long radius curves the saving per thousand board feet mile would be greater and road construction more justifiable. Road construc-

TABLE 2.—MACHINE RATE FOR TWO-TON TRUCK

(Gasoline engine—single axle)

Fixed Costs per Hour			
Truck investment	$2,500.00		
Trailer investment (single axle)	1,500.00		
Total	$4,000.00		
Less: 10 tires @ $110.00	1,100.00		
Amount to be depreciated	$2,900.00 @ 5,000 hrs.		$ 0.58
License, insurance and taxes			0.06
Lubrication, inspection, adjustment, washing and garage expense			0.16
Driver's wages (50 hrs. per week @ $0.85)			0.94
10 percent of wages for Social Security, Etc.			0.09
Total Fixed Cost			$ 1.83
Operating Costs per Mile	**Pavement**	**Gravel**	**Dirt**
Repairs, tires, oil and maintenance	$0.060	$0.075	$0.085
Fuel	0.034	0.043	0.040
Total operating cost	$0.094	$0.118	$0.125

TABLE 3.—MACHINE RATE FOR THREE-TON TRUCK

(Gasoline engine—single axle)

Fixed Costs per Hour			
Truck investment	$4,600.00		
Trailer investment (single axle)	2,000.00		
Total	$6,600.00		
Less: 10 tires @ $130	1,300.00		
Amount to be depreciated	$5,300.00 @ 7,500 hrs.		$ 0.71
License, insurance, and taxes			0.07
Lubrication, inspection, adjustment, washing and garage expense			0.18
Driver's wages (50 hrs. per week @ $0.85)			0.94
10 percent of wages for Social Security, etc.			0.09
Total fixed cost			$ 1.99
Operating Cost per Mile	**Pavement**	**Gravel**	**Dirt**
Repairs, tires, oil and maintenance	$0.060	$0.075	$0.085
Fuel	0.050	0.065	0.055
Total operating cost	$0.110	$0.140	$0.140

TABLE 4.—MACHINE RATE FOR SIX-TON TRUCK

(Diesel engine—tandem axle)

Fixed Costs per Hour			
Truck investment	$14,000.00		
Trailer investment (tandem axle)	4,500.00		
Total	$18,500.00		
Less: 18 tires @ $160	2,880.00		
Amount to be depreciated	$15,620.00 @ 10,000 hrs.		$ 1.56
License, insurance and taxes			0.13
Lubrication, inspection, adjustment, washing and garage expense			0.21
Driver's wages (50 hrs. per week @ $1.10)			1.21
10 percent of wages for Social Security, etc.			0.12
Total fixed cost			$ 3.23
Operating Costs per Mile	**Pavement**	**Gravel**	**Dirt**
Repairs, tires, oil and maintenance	$0.080	$0.105	$0.115
Fuel	0.030	0.035	0.030
Total operating cost	$0.115	$0.140	$0.145

tion which shortens the hauling distance or connects existing private roads is very desirable and economical. On sustained yield operations, part of the road expense can be written off on forestry operations, particularly fire protection.

The longer the hauling distance the greater the difference in cost between the large and small trucks. If the trucks and loading equipment are kept in fairly constant use throughout the working day, the big trucks will haul saw timber as cheaply as the small trucks on the shortest hauls. The loading cost per thousand board feet for stiff-boom loaders with small trucks is about the same as the cost for swing-boom loaders with big trucks; also the truck standby cost per thousand board feet is approximately the same. Therefore, where the volume of saw timber is large, it is more economical to use large trucks on all distance hauls.

Discussion

Harold E. Holman (National Production Authority): Have you made any studies of the economies of sprinkling roads?

Mr. Tufts: No, we haven't. The dust hazard on dirt and gravel roads is very bad during dry seasons, and although it has been the cause of only a few accidents, it does slow down the hauling operation. Sprinkling the roads might be worthwhile.

J. A. Hall (Director, Forest Products Laboratory): Why are the trips per day fewer for the small trucks?

Mr. Tufts: The time studies showed a slower speed for small trucks as compared to large trucks on the same road class. The small trucks are usually under-powered for the loads they carry.

Charles R. Lockard (N. E. Forest Experiment Station): Is there any difference between fuel costs running over dirt and paved roads?

Mr. Tufts: No. Although the fuel consumption is less per mile on paved roads than on dirt roads, the State Fuel tax adds enough to the fuel cost on paved roads so that the fuel cost for both road classes is the same.

Mr. X: Why are the fuel costs less for dirt roads than gravel roads?

Mr. Tufts: Approximately the same fuel mileage is realized on dirt roads as on gravel roads. But about half the gravel roads in the area are state highways for which a fuel tax must be paid.

C. R. Silversides (Abitibi Power & Paper Company): (a) What is the length of hauling season in days per year, (b) how much is hauled, and (c) do costs given in paper for hauling on State versus private roads include road construction costs?

Mr. Tufts: (a) All year round—240 to 255 days per year. (b) 3,500 board feet per load Doyle scale —4 trips per day—14,000 board feet per day, 250 days—3,500,000 annually. (c) No. Maintenance costs of company roads are charged to forestry operations. No company roads have been built where state roads can be used unless the savings in hauling costs can pay for the road construction within 10 years.

Fred E. Dickinson (Yale University): What is the cost of building roads?

Mr. Tufts: Road construction costs vary a great deal. Near Crossett where the land is very flat and frequent bridges have to be built the cost runs about $4,000 per mile for a 22 foot-wide road. Farther north Southern has built 18 foot-wide roads for as little as $960 per mile. In both cases this includes right-of-way clearing, grading, and graveling. Half the cost at Crossett is in graveling because the gravel has to be hauled long distances.

Mr. Holman: Would a road builder follow radius and grade map?

Mr. Tufts: No. Grade is practically no problem at all, and our new roads are built in straight lines as much as possible. Much of the road construction follows old trails or old county roads which have short radius curves. This is often the only economical way to cross creek bottom areas.

Robert C. Fraunberger (Philco Corporation): How did you arrive at the depreciation hours per year of 5,000, 7,500, and 10,000 hours, given in Tables II, III, and IV?

Mr. Tufts: Based on 10 hours per day and 250 days per year.

Mr. Fraunberger: Does that mean that you write off a two-ton truck in two years?

Mr. Tufts: Yes, that is the minimum allowed by the government, but few two-ton trucks last that long.

T. S. Veazey, Jr. (Anaconda Copper Mining Company): How do you pay your truck drivers?

Mr. Tufts: By the hour, from $1 to $1.14.

Mr. Fraunberger: Have you tried "preloading" of trailers having several trailers to one truck tractor?

Mr. Tufts: Preloading pole trailers is impractical. The stiffback trailer can be preloaded, but it puts a heavy strain on the landing gear. The loading operation loses its mobility, and a trailer can be loaded in almost the same time it takes to spot an empty trailer and hook up a loaded one.

Richard A. Hale (R. H. Hale Logging & Lumber): Do you load empty trailers piggy-back on the return trip?

Mr. Tufts: The Southern Lumber Company has pole trailers which they load piggy-back for the return trip to the woods. At Crossett we have a stiffback trailer which is too unhandy to load piggyback. Southern reports a big saving in tire cost and trailer maintenance since they have gone to the piggy-back system.

Howard H. Coe (Stanley Works): What is average loading time per thousand board feet loading full length logs?

Mr. Tufts: The Southern Lumber Company averages seven minutes per thousand board feet with a heel boom loader. Their loads average about 3,500 board feet so that 24½ minutes is their normal loading time. At Crossett we use end tongs, and our loading time is about the same as Southern's. With end tongs we are loading the same scale as fast in short logs as in long logs. However, we are not very experienced in handling long length logs yet.

Mr. X: Where did you get the 85,000 pound rating for a six-ton truck?

Mr. Tufts: The 85,000 pound nominal gross combination weight is the consensus of opinion expressed by the manufacturers of the experimental log truck and trailer tested at the Crossett Lumber Company (Four Wheel Drive Auto Company and Birmingham Trailer Company, November, 1950). Mr. Mety also concurred in this weight for his log trucks at the Southern Lumber Company.

Circular Sawmills in the Tennessee Valley Region

PAUL H. LANE, *Staff Forester, Division of Forestry Relations, Tennessee Valley Authority, Norris, Tennessee*

Small circular sawmills produce the bulk of the lumber in the Tennessee Valley region. How the operators of these mills harvest and process the timber resource determines, to a large extent, the future of the region's forests and wood using industries. This paper, based on a study of 58 circular mills, presents some statistics on mill operation and attempts to point out remedies for some of the basic problems.

Introduction

THE Tennessee Valley region is an important source of hardwood lumber and ties. The area's 14 million acres of timberlands yield about a billion board feet annually and support a $200 million forest products industry. Circular sawmills are the mainstay of this industry.

Three groups of mills are generally recognized: (1) band mills, (2) non-commercial circular, and (3) commercial circular mills.

The band mills are well managed and produce high quality factory and yard lumber. But there are only 18 band mills in the region. Their combined annual output, estimated at 100,000,000 board feet, represents only 10 percent of the total production.

The non-commercial circular mill is a part-time operation; lumber production is not the primary interest of the owner. This type of mill normally produces less than 250,000 board feet a year; its principal product is low-grade material for local construction. There are about 2,800 such mills in the area and as a group they produce about 200,000,000 board feet annually (20 percent of total).

By far the most important type is the commercial circular mill. For the owners of these mills sawmilling is the principal business interest. There are about 1,200 such mills in the region—less than half as many as non-commercial—but their annual output is about 700,000,000 board feet, 70 percent of the total. They are the principal processors of the forest crop and very largely determine the kind of sawn products available for industry. They also play an important role in supplying the country's hardwood lumber needs during national emergencies.

It was TVA's interest in forest resource development and lumber production for national defense that led to this study of commercial circular sawmills. We wanted to find out something about their operation, what kind of products they turned out, what kind of logs they processed.

The primary objective was to collect factual data that would be helpful to the lumber industry and to others who are interested in conserving and developing the forest resource. Recognizing that sawmill operators are generally skilled in the mechanics of mill operation, we put primary emphasis on information about sawmill management and the character of the logs being sawn.

The study was planned and carried out by TVA[1] in cooperation with the Southern Forest Experiment Station of the U. S. Forest Service. It covered 58 circular mills selected at random throughout the region (a 5 percent sample of the total mill population). Distribution of the sample mills is shown in Fig. 1.

Information collected at each study mill included data on equipment, milling practices, log procurement, lumber production, log sawing time, character of logs, lumber grade recovery, products, and marketing.

Mill Operation

It is recognized that no two circular mills are alike in operating characteristics. Nevertheless, there is a general pattern according to mill size. So to begin with mills were grouped into three broad size classes: (a) small, (b) medium, and (c) large, on the basis of their equipment and over-all productive capacity. Some of the significant differences among mills in these three classes are shown in Tables 1 and 2.

There is a significant trend in the region from the portable operation to the small stationary mill. In 1946, 70 percent of the circular mills were portable; four years later the percentage had dropped to 50 (based on sample mills). The reasons for this shift are fairly evident: cheaper rates are persuading more and more operators to use electric power; a better mill site can be selected; transportation and marketing facilities for logs, lumber, and mill by-products are improved; the labor supply is more stable (6).

Local conditions may determine the method of operation for any particular mill; but regardless of

[1] Planned and directed by W. N. Darwin, Chief of Forest Utilization Section, Tennessee Valley Authority. Field work by B. C. Cobb, G. H. Fechner, and the author, July 1949 to June 1950.

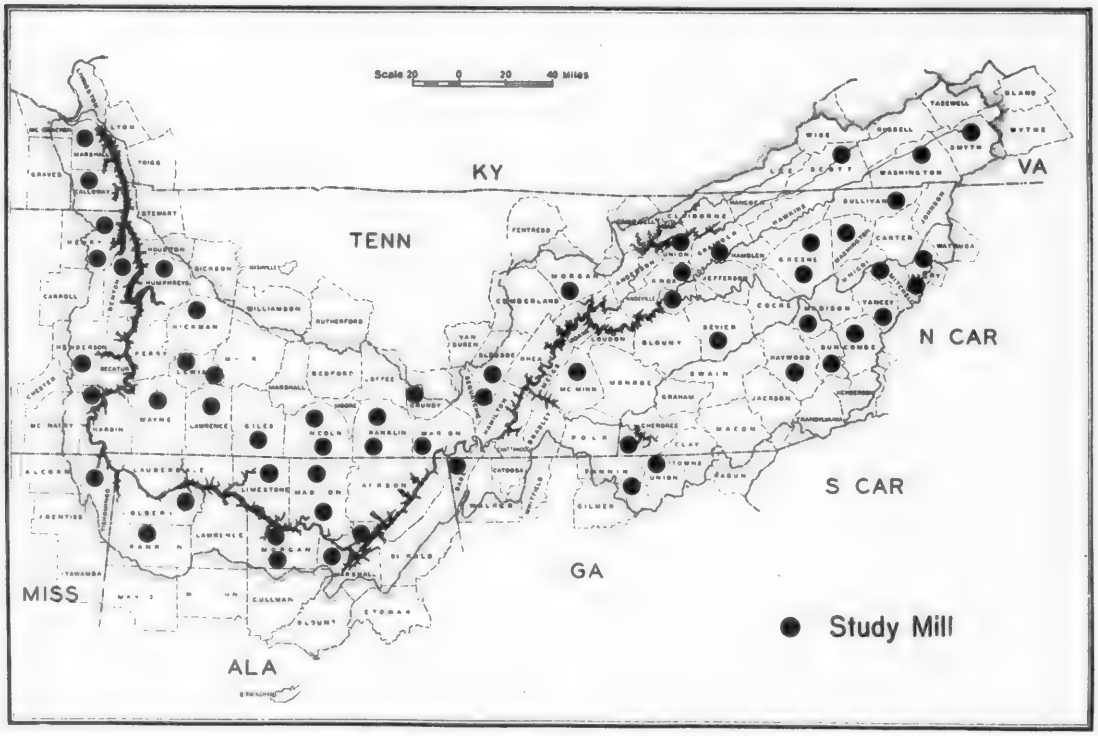


Fig. 1.—Location of sample sawmills.

these local variations, sawmill profits depend largely on the managerial skill of the operator and the kind of logs and the equipment he has to work with.

Mill Equipment

Circular sawmills have always operated with the least possible amount of equipment. Few other industries processing raw material have such a low capital-labor ratio. The present ratio of capital investment to labor cost in the sawmill business is about 1 to 10. The national average for all industries is about 3 to 2. Sawmills invest only $1,000 in equipment for each employee, whereas the statewide average for all industries in Tennessee is about $12,000.

TABLE 1.—OPERATING CHARACTERISTICS OF CIRCULAR SAWMILLS ACCORDING TO MILL SIZE CLASS

Mill Operation	Mill Class			
	Small	Medium	Large	Average
	Percent			
LOCATION				
Portable	77	46	33	58
Stationary	23	54	67	47
OWNERSHIP				
Individual	65	57	17	55
Company	35	43	83	45
OPERATION (Accounting)				
Force account	100	91	83	93
Contract	0	9	17	7
SOURCE OF LOGS				
Stumpage	37	75	84	62
Log purchase	30	5	16	20
Custom or contract	33	20	0	18
PRODUCTS				
Boards	68	84	90	83
Timbers	8	9	9	9
Ties	24	7	1	8
SEASONING				
Sold green	77	39	26	41
Air dried	23	61	74	59
MARKETS				
Local use	31	20	19	21
Local concen. yards	45	30	14	28
Intra-state shipment	6	27	25	24
Inter-state shipment	18	23	42	27
SALES METHOD				
Retail	31	29	25	28
Wholesale	69	71	75	72
LUMBER SALE				
Mill run	20	9	0	8
On grade	80	91	100	92

TABLE 2.—PRIMARY EQUIPMENT OF CIRCULAR SAWMILLS ACCORDING TO MILL CLASS

Mill class	Type of Power Unit in Percent				Average size of headsaw (Inches)	Percent of mills having edgers	Percent of mills having cut-off saws
	Gasoline	Diesel	Electric	Steam	Portable and Stationary Combined		
SMALL							
Portable	63	38	0	0			
Stationary	25	0	75	0	50	53	35
MEDIUM							
Portable	50	50	0	0			
Stationary	26	42	32	10	54	89	69
LARGE							
Portable	50	50	0	0			
Stationary	0	50	25	25	58	100	100
AVERAGE—All							
Portable	55	45	0	0			
Stationary	22	30	37	11	54	79	62

However, since World War II there has been an encouraging trend among sawmill operators toward mechanization, with larger investments in new and better equipment (*5*). High labor costs have been the major contributing factor. Over 80 percent of the 58 sample mills had purchased new power units within the last five years and over 50 percent had purchased new mills. The trend is apparently toward electric power. More stationary mills use electric power units than any other type (Table 2).

About 25 percent of all commercially operated circular mills are inadequately equipped for the job they are trying to do. Some have too little power; others lack such basic equipment as edgers, dust chains, head blocks and log handling facilities; others are struggling along with worn out and inefficient equipment. In addition, a majority of all circular mills could profitably invest in such equipment as slab conveyors, spare headsaws, and log cleaning and handling equipment. As might be expected, the majority of inadequately equipped mills are in the small size class.

But as important as equipment additions might be, of even greater importance is this consideration: Is the operator getting maximum production out of the equipment he has?

Lumber Production

Headsaw operating time is the key to mill production. Although the larger circular mills generally produce more lumber per operating day than small mills, the principal reason is *not* because they are larger but because they have less delay time. As shown in Table 3, the mill-hour production of small mills (including delay time) is only one-half that of the large mills. However, mill-hour production for about 30 percent of the small mills is higher than for some of the large mills if based on actual sawing time only. Man-hour production is significantly greater for the small mills.

The delay or "shut-down" time for the average mill is 2 hours per day, leaving 6 hours of actual sawing time (Table 4). This delay reduces potential daily production by 2,000 board feet, worth about $120. Each minute of shut-down time, therefore, reduces gross returns by $1.00.

TABLE 4.—PRIMARY CAUSES FOR DELAY-TIME AT CIRCULAR SAWMILLS

Cause	Delay time minutes per 8-hr. day
Filing and changing saw	40
Out of logs	15
Moving slabs and lumber	15
Weather	12
Oiling and fueling	10
Dust chain repair	10
Belt repairs	7
Power unit repair	4
Other equipment repairs	4
Miscellaneous	3
TOTAL	120 (2 hrs.)

Of course delay time cannot be entirely eliminated. Part of the working day must be used for equipment repair and maintenance. However, the average mill operator can reduce lost time by about 50 percent through better management.

Saw filing, the largest single cause of delay time, adds up to 40 minutes per day at the average mill. It can be materially reduced by having spare saws and changing them rather than stopping to file them. When water is available, the need for filing can be substantially reduced by washing dirt and grit from the logs. Some of the sample mills that had spare saws and log washing equipment lost only 5 minutes per day changing saws.

TABLE 3.—LUMBER PRODUCTION OF CIRCULAR SAWMILLS ACCORDING TO MILL SIZE CLASS

Mill class	Board feet per mill-hour		Board feet per man-hour		Average size of crew
	Total operating time[1]	Actual sawing time only[2]	Total operating time[1]	Actual sawing time only[2]	
Small	553	811	125	180	4
Medium	751	1032	120	167	6
Large	1088	1264	113	130	10
Average	728	991	121	168	6

[1]Includes delay time.
[2]Headsaw operating time only.

Running out of logs, another principal cause of delay time, can be virtually eliminated by good mill management. Forty percent of the study mills lost no sawing time due to lack of logs. The remaining 60 percent had inadequate facilities or manpower for handling and storing logs.

Labor saving equipment to move slabs and lumber—roll-ways, skids, and conveyors—would be a profitable addition at many mills. Worn out belts and dust chains are a frequent cause of shutdowns. Although heavy rains usually close down all types of mills, many are able to work through light, intermittent showers by providing at least a temporary wooden shelter to protect belts and crews. One third of the mills lack equipment shelters of any kind.

Adequate facilities and good equipment maintenance are sound investments. Each additional minute of sawing time means another dollar in gross return without any additional labor cost.

In addition to increasing daily output, mills can increase annual production by working more days. The average circular mill operates only 120 days per year. This is but 60 percent of capacity, assuming a total of 240 working days per year with two months (40 days) off for bad weather and major repairs. A standard of 200 working days a year is a reasonable goal for circular mills. Only about 20 percent of the mills reach it.

Production Costs

More operating time not only increases mill output; it also reduces the cost of production. A detailed cost analysis was not possible for each sample mill; however, enough information was collected to permit a reliable estimate of production costs for the average circular mill.

The four major cost items—capital, labor, materials, and overhead—were allocated to the various sizes and species of logs on the basis of sawing time. Capital costs were based on the total investment in equipment depreciated in 10 years, with a 10 percent salvage value and an interest rate of 6 percent. Labor costs assumed a crew of six men with an average hourly wage rate of $1.045. This rate was computed by using $1.50 for sawyer, $0.85 for edgerman and one other skilled worker, and $0.75 for three mill hands. Material costs (excluding logs) were based on estimated costs per M.b.m. as follows: fuel, grease, and oil $0.25; small tools and operating supplies $0.10; repair parts $0.35. Overhead costs represent a combined total of salary for management, office and business expenses, taxes and insurance, lumber transportation and marketing costs, and such miscellaneous costs as bad debts, legal expenses, and moving the mill. Management salary was computed at $100 per week, taxes and insurance at 1½ percent on one-half the capital investment, lumber transportation at $5.00 M.b.m., and other expense at 20 percent of capital.

Table 5 shows estimated production costs for the dense hardwoods. Production costs for pine and soft hardwoods are approximately 10 percent less per M.b.m. because of sawing-time differential. The pronounced effect of log diameter is shown in the table. For example, increasing the diameter from 8 to 10 inches, reduces production costs by *more than eight dollars per M.b.m.* Costs range from $72 for 5-inch logs to $18 for 20-inch; the average (12 inches DIB) is about $24.

TABLE 5.—ESTIMATED COSTS OF PRODUCING DENSE HARDWOOD LUMBER AT CIRCULAR MILLS

Log DIB (Inches)	Production costs per M.b.m.				
	Capital	Labor	Materials[1]	Overhead	Total
5	$ 4.48	$37.46	$ 2.43	$27.68	$72.05
6	3.23	26.98	1.75	21.34	53.30
7	2.48	20.74	1.35	17.56	42.13
8	2.08	17.40	1.13	15.54	36.15
9	1.74	14.53	.94	13.80	31.01
10	1.54	12.90	.84	12.81	28.09
11	1.40	11.74	.76	12.11	26.01
12	1.29	10.77	.70	11.52	24.28
13	1.18	9.85	.64	10.97	22.64
14	1.12	9.37	.61	10.67	21.77
15	1.07	8.99	.58	10.44	21.08
16	.86	7.19	.47	9.36	17.88
17	.84	7.02	.46	9.25	17.57
18	.83	6.98	.45	9.23	17.49
19	.85	7.12	.46	9.31	17.74
20	.92	7.73	.50	9.68	18.83

[1]Excluding cost of logs.

Log Values

In addition to knowing production costs, the sawmill operator must also know the value of his logs. How much are logs worth on the basis of lumber grade yield and the cost of producing that lumber?

During the mill study 9,342 logs were classified and the resulting 540,770 board feet of lumber was graded by NHLA and SPIB standards. Values for the various species and sizes of logs were determined by subtracting production costs (Table 5) and a fixed profit and risk margin from the market value of the graded lumber. Average lumber grade

TABLE 7.—LUMBER PRICES USED FOR CALCULATING LOG AND LUMBER VALUES[1]

Plain red oak	Price per M.b.m.	Yellow poplar	Price per M.b.m.	Yellow pine	Price per M.b.m.
FAS	$110.00	FAS	$120.00	B and Better	$ 90.00
Select	104.50	Select	114.00	C	85.50
No. 1 Com.	77.00	Saps	108.00	No. 1	63.00
No. 2 Com.	55.00	No. 1 Com.	84.00	No. 2	45.00
Sound—wormy	55.00	No. 2A	60.00	No. 3	36.00
No. 3A	38.50	No. 2B	42.00	No. 4	22.50
No. 3B	27.50	No. 3	30.00		

[1]Average selling price of 4/4 lumber, rough-green, delivered in Knoxville, Tennessee, based on quotations from three leading manufacturers, February 1951.

TABLE 6.—AVERAGE LUMBER GRADE RECOVERY FROM CIRCULAR-SAWN LOGS IN THE TENNESSEE VALLEY REGION

Species	LUMBER GRADE YIELD (PERCENT)									BASIS		
	FAS (H & Btr. Pine)	SEL. (C Pine)	No. 1 Com.	SAPS	No. 2 Com. (2A Pop.)	S-W (2B Pop.) (No. 3 Pine)	3A (No. 4 Pine)	3B	Tie or Timber	No. Logs	Mill Tally Bd. Ft.	Av. Log DIB
Ash	13	13	29	0	29	1	10	5	*	91	6,672	12.3
Basswood	17	6	30	0	37	0	7	3	0	169	14,179	12.9
Beech	3	3	24	0	35	*	16	7	12	208	19,873	14.3
Buckeye	8	3	23	0	44	0	13	9	*	71	6,032	12.8
Cedar	0	0	42	0	56	0	0	0	2	237	2,170	5.6
Cheetnut (dead)**	1	2	13	0	34	11	17	21	1	130	12,423	14.5
Gum, black	5	2	19	0	39	1	15	7	12	92	9,555	12.2
Gum, sweet	2	1	19	0	31	0	7	2	38	107	6,956	11.8
Hickory	3	1	19	0	28	1	21	12	15	179	10,834	11.8
Maple, hard	7	7	27	0	35	1	16	7	*	165	13,235	12.8
Maple, soft	6	5	24	0	45	1	11	4	4	54	3,127	11.6
Oak, black	5	4	15	0	20	1	21	15	19	1234	77,140	11.6
Oak, chestnut	2	3	13	0	19	23	14	16	10	546	40,460	12.3
Oak, post	1	1	6	0	15	4	19	18	36	202	8,729	10.2
Oak, red, Northern	17	10	26	0	19	1	11	6	10	401	44,633	14.3
Oak, red, Southern	5	3	17	0	21	1	13	10	30	316	19,998	11.8
Oak, scarlet	2	2	12	0	20	1	23	19	21	872	48,487	11.4
Oak, white	4	2	14	0	21	3	18	13	23	950	53,188	11.0
Pine, loblolly	10	4	20	0	60	8	*	0	*	687	23,656	8.3
Pine, shortleaf	8	4	24	0	45	12	*	0	7	1627	52,788	8.2
Pine, Virginia	*	*	11	0	67	9	1	0	12	137	3,560	7.8
Walnut, black	4	2	14	0	54	0	24	1	1	50	2,124	10.7
Yellowpoplar	1	2	29	6	37	21	3	1	*	979	65,635	12.1

*Less than 0.5 percent.
**Graded WHND.

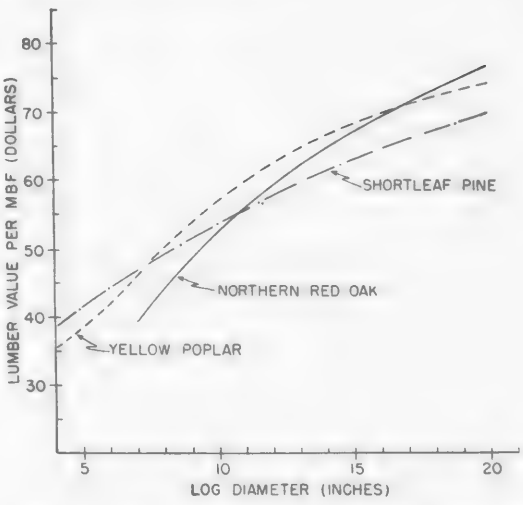


Fig. 2.—Lumber values for three principal species in the Tennessee Valley, based on February 1951 lumber prices and grade recovery by log size.

recovery for the major species is shown in Table 6. Lumber values were computed on the basis of grade recovery according to log sizes and the prices shown in Table 7. Fig. 2 illustrates these values for three principal species.

Log values were derived by deducting log production costs (Table 5) from lumber values. Log values for northern red oak, one of the principal species, are shown in Fig. 3.

Log Grades

The lumber grade recovery from a large group of logs provides a reliable over-all picture of the region's sawlogs. However, the individual sawmill operator should be able to predict what kind of lumber he can expect from any given lot of logs. Only in this way can he determine a price that is fair to the timber grower and at the same time will insure a reasonable profit. As Lockard (*1*) points out, grading sawlogs is a means to this end.

Any experienced sawyer can judge the value of a log on the carriage. The important thing is to train loggers and log buyers to recognize the value of logs before they reach the log deck. A practical log grading system is one way to keep marginal and unprofitable logs away from the mill.

Over 9,000 logs were graded during the study by methods developed by the U. S. Forest Products Laboratory (*7*) and the Southeastern Forest Experiment Station (*3*). Log defects were classified according to USDA Handbook No. 4 (*2*). In general, the hardwood log grades classify logs according to the expected yield of No. 1 Common and Better lumber. Log grades 1, 2, and 3 represent standard factory-lumber logs. Grade 4 logs are too defective for factory lumber, but still not cull. Grade 5 logs are culls containing less than 50 percent sound mate-

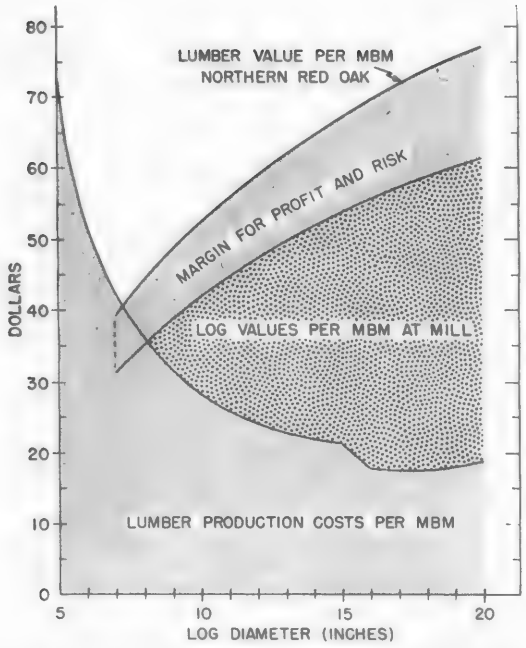


Fig. 3.—Value of Northern red oak logs delivered to circular mills, based on lumber production costs and value of lumber (February 1951) produced from the various sizes of logs. Profit margin is assumed to be 20 percent of lumber value. Sharp drop in production cost from 15- to 16-inch logs is due to increase of average log lengths.

rial. Grade 6 are below sawlog size, less than 8 inches in diameter and 8 feet in length. Tables 8 and 9 show the lumber yield and distribution of logs according to grade.

Even after logs have been graded, considerable skill on the part of the sawyer, edgerman, and cut-off saw operator is required to turn out all of the high-quality boards that a particular log is capable of yielding. The importance of grade sawing was pointed out by the assistant chief inspector of the NHLA, L. C. Nicely (*4*), who assisted with the study.

Circular mills can manufacture lumber that is equally as good as band-sawn lumber insofar as dimensional accuracy is concerned. Of the half-million board feet graded during the study, less than 2 percent failed to meet NHLA and SPIB standards for thickness and width. Thickness variation within these grading standards was not studied. However, circular mills often fail to get the maximum yield of quality boards. Grade 1 logs will yield a good percentage of No. 1 Common and Better lumber by almost any method of sawing. The real opportunity for profit is in getting the maximum number of FAS and Select boards. The study indicated that a majority of circular mills could frequently up-grade No. 1 Common boards by better edging or end trimming without appreciably reducing footage yield.

TABLE 8.—THE LUMBER GRADE YIELD FROM CIRCULAR-SAWN LOGS ACCORDING TO LOG GRADE (IN PERCENT)

Species	Log Grade 1			Log Grade 2			Log Grade 3			Log Grade 4			Log Grade 5			Log Grade 6		
	1 Com. & Btr.	2 C & Below	Tie & Timber	1 C & Btr.	2 C & Below	Tie & Timber	1 C & Btr.	2 C & Below	Tie & Timber	1 C & Btr.	2 C & Below	Tie & Timber	1 C & Btr.	2 C & Below	tie & Timber	1 C & Btr.	2 C & Below	Tie & Timber
Ash	72	28	0	48	52	0	30	68	2	0	100	0	0	0	0	0	100	0
Basswood	73	27	0	46	54	0	23	77	0	0	0	0	44	56	0	9	91	0
Beech	56	34	10	37	52	11	22	67	11	7	69	24	4	0	100	0	0	0
Buckeye	54	46	0	37	63	0	18	82	0	2	98	0	0	100	0	0	100	0
Gum, black	70	22	8	28	62	10	7	72	21	1	99	0	0	100	0	0	100	0
Gum, sweet	78	22	0	32	34	34	15	41	44	1	60	39	0	100	0	0	18	82
Hickory	61	39	0	32	45	23	19	68	13	2	86	12	0	83	67	0	24	76
Maple, hard	64	36	0	49	51	0	22	77	1	9	91	0	0	100	0	0	100	0
Maple, soft	64	36	0	40	55	5	15	81	4	31	69	0	4	38	58	0	100	0
Oak, black	59	33	8	26	57	17	9	65	26	1	80	19	*	76	24	11	52	37
Oak, chestnut	49	46	5	25	70	5	5	80	15	1	88	11	6	85	9	1	67	32
Oak, post	0	0	0	26	44	30	9	49	42	1	65	34	0	100	0	2	83	15
Oak, red, Northern	73	24	3	46	43	11	14	61	25	3	67	30	0	100	0	8	25	66
Oak, red, Southern	52	28	20	33	38	29	15	51	34	1	81	18	0	100	0	5	28	67
Oak, scarlet	65	28	7	35	54	11	10	59	24	2	71	27	6	72	22	2	68	30
Oak, white	63	35	2	31	51	18	11	59	30	2	77	21	2	53	45	4	55	41
Pine, loblolly	91	19	0	40	60	0	10	90	0	0	0	0	0	100	0	11	88	1
Pine, shortleaf	77	16	7	46	44	10	16	75	9	0	0	0	0	0	0	15	83	2
Pine, Virginia	100	0	0	36	50	14	7	84	9	0	0	0	0	0	0	5	80	15
Walnut, black	64	36	0	23	77	0	6	94	0	0	0	0	0	0	0	0	67	33
Yellowpoplar	67	33	0	44	56	0	21	79	*	7	93	*	5	95	0	10	89	1

*Less than 0.5 percent.

TABLE 9.—DISTRIBUTION OF CIRCULAR-SAWN LOGS ACCORDING TO LOG GRADE (IN PERCENT)

Species	GRADE 1		GRADE 2		GRADE 3		GRADE 4		GRADE 5		GRADE 6	
	Logs	Vol.	Logs	Vol.	Logs	Vol.	Logs	Vol.	Logs	Vol.	Logs	Vol.
Ash	25	46	33	32	35	20	6	2	0	0	1	*
Basswood	24	40	48	42	20	17	0	0	2	1	1	*
Beech	3	10	30	40	54	44	12	6	1	*	0	0
Buckeye	20	35	28	28	44	31	4	4	3	2	1	*
Gum, black	10	20	25	34	47	33	13	9	4	4	1	*
Gum, sweet	3	4	28	33	55	50	15	10	2	2	2	1
Hickory	3	6	20	24	57	57	17	12	1	*	2	1
Maple, hard	11	23	32	39	46	32	8	5	1	*	2	1
Maple, soft	9	21	24	32	46	34	13	9	4	2	4	1
Oak, black	8	22	18	25	43	36	22	13	1	1	8	3
Oak, chestnut	6	14	22	35	53	42	10	7	2	1	7	1
Oak, post	0	0	8	12	46	54	26	26	2	1	18	7
Oak, red, northern	25	55	24	22	40	20	5	2	*	*	6	1
Oak, red, southern	5	14	36	45	44	28	14	9	*	*	11	4
Oak, scarlet	2	5	18	22	44	44	29	23	4	3	3	3
Oak, white	4	14	15	24	57	49	12	9	2	1	10	3
Pine, loblolly	6	17	17	32	35	37	0	0	*	*	42	14
Pine, shortleaf	8	21	16	23	31	36	0	0	0	0	45	20
Pine, Virginia	1	1	7	15	42	54	0	0	0	0	50	30
Walnut, black	6	13	26	40	62	45	0	0	0	0	6	2
Yellowpoplar	9	22	25	32	47	37	9	6	2	1	8	2

*Less than 0.5 percent.

Summary

In the Tennessee Valley region, circular sawmills are a vital part of the forest industry. These small mills are potentially capable of processing all of the timber the resource can supply and of manufacturing it to meet the requirements of industry. The data indicate that dimensional quality of lumber is not the major problem of the operator.

Circular mills, as a group, need more managerial skills and more working capital. Operators need to know more about log quality and forest management. Better standards are needed to control quality of production. Capital is needed for grading, seasoning, and marketing lumber and for adequately equipping the mills.

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Discussion

Orvel A. Schmidt (Pennsylvania State College): What is the average production of the small mills?

Mr. Lane: The average is about 6,000 board feet per day.

Mr. Schmidt: Are the mills of temporary or permanent nature?

Mr. Lane: Approximately 50 percent are portable and 50 percent are stationary.

Mr. Schmidt: Does your figure include the lost time in the woods?

Mr. Lane: No, our figures on lost time are for working time at the mill.

Mr. Schmidt: Does the profit of $10.00 net from additional one hour of work vary with the species?

Mr. Lane: That $10.00 figure is based on the average production cost of red oak. Profit does vary somewhat with species because of price differentials for a given grade and difference in production rates.

Mr. Schmidt: How will the education of mill men to grade logs affect the conditions of our forests as to quality control?

Mr. Lane: I think that in the long run, grading logs will improve stand conditions by helping to channel logs into their best use. For the same reason this should implement quality control at the mill.

Mr. Schmidt: Would it not be better to think of grade even if some added thickness must be sacrificed?

Mr. Lane: Yes, I think that the first step is to get the maximum yield of the better grades. Thickness control is important but it seems to me that this is a refinement to be carried out after some of the basic ills of mill operation are corrected.

Walton R. Smith (Walton Lumber Company Inc.): Merely the education of the mill man to grade logs is not likely to affect forestry practices very much. If log buyers, however, will realize the difference in value between the logs of the different grades and will pay accordingly, the mill man will soon realize that the young, immature, knotty logs will not pay their way but that the mature logs will usually bring a good profit. After all, the profit incentive will control our forestry practices, whether we are idealists or not.

Statistical quality control is too complicated for the average sawmill man to comprehend. We need to develop something of simpler terminology and easier application than the methods we now use, if the sawmill man is to carry on.

Grade is far more important in lumber values than a little loss in footage by a little extra thickness. More money is lost by the small sawmill men who sell to me by failure to saw for grade than by anything else. Another loss that is appreciable is from thin lumber, which again is a grade loss.

Robert C. Fraunberger (Philco Corporation): In Table 8—Grades and Yield; was the lumber inspected by NHLA inspectors?

Mr. Lane: Yes, we contracted with the NHLA to inspect the lumber on this study.

Mr. Fraunberger: Have you given the log run totals for this data to compare with the log grade figures?

Mr. Lane: No, because we have not completed the analysis of our log grade data. However, from this chart you will note that the average mill run yield for hardwood logs is 28 percent No. 1 Common and Better; 58 percent No. 2 Common and lower; and 14 percent ties and timbers.

Mr. Fraunberger: Does it pay the small operator to grade?

Mr. Lane: We certainly think so. As I indicated in the paper, grading logs is one way of controlling log quality to insure a reasonable profit.

I. V. Anderson (U. S. Forest Service): How do you propose to educate small mill men to use of these grades?

Mr. Lane: Through a program of education and demonstration.

Mr. Anderson: Would you use farm foresters, lumber association representatives, your own educational organization or just what?

Mr. Lane: I think that to be successful it should be a joint program of the various public forestry agencies, both State and Federal, with industry. We have participated in several such demonstrations recently that were sponsored jointly by the State Forestry school, the State Forester and a lumber industry trade association. To date we have found mill operators very interested and receptive to the idea of grading sawlogs.

Mr. Smith: I am trying an experiment in educating the small sawmill operator not only in log grades but in selective cutting, and lumber grading. I buy poplar lumber almost exclusively and I purchase it all on grade with quite a differential in price between the better and poorer grades. The operators are learning that they do not break even if they cut small, immature, knotty timber but that they make a good profit if they operate in mature stands that will produce grade. I am instructing them in grading lumber and sawing for grade through personal contact in my yard, by visiting their operations, and by a series of letters on grading lumber that I am now sending out. (Sort of like a correspondence course.) I believe that the key to the small sawmill problem is through the pocketbook and that we will solve the problem when we can get a majority of the concentration yards (pine and hardwood) to buy only on grade with a substantial difference in price between the high and low grades. The concentration yards will find that they are not gambling nearly so much when they buy on this basis and they will be doing a real service to promoting better forestry. Purchasing logs by log grades has the same effect.

Charles S. Walters (Illinois Agricultural Experiment Station): Are the production cost figures you have presented estimates or are they actual data? Most of the small mill operators in the Central Hardwood Region—perhaps those cutting less than 500 MBM a year—do not know what it costs to produce lumber. What they need most is a simple record-keeping system that will enable them to determine production costs.

Mr. Lane: The production costs are based on average data for the 58 mills. Actual data were collected on sawing time and labor costs. Capital, materials, and overhead costs are estimates based on information from a few selected operators. It was not possible to make a detailed cost study at each mill.

Mr. Smith: I do not have any detailed information on small sawmill costs, but in questioning small sawmill operators who sell lumber to me, they feel that it costs them $30.00 per M. to deliver the lumber to my yard. They pay from $10.00 to $15.00 stumpage and figure $3.00 to $5.00 for the haul. This would make their cost of milling from $10.00 to $17.00 per M. Based on present labor costs, it is my belief that it averages around $15.00.

Mr. Schmidt: On log grades, is it feasible for these mills to handle grade 3 logs at a profit?

Mr. Lane: That depends considerably on the products produced from the log. Certainly the chances for some profit on a grade 3 log are better if the heart center can be used for ties or timbers. Under present conditions a mill could not operate

with a profit on grade 3 logs alone. Certainly grade 3 logs below 10 inches are unprofitable.

Richard L. Burkhart (Swain Industries): Will the profit for the sawmill man be more if those top grade logs were sold for veneer instead of being sawn into lumber? Our experience shows that on red oak cut in southern Kentucky, at current prices a yield of $31.25 per thousand board feet (Doyle) more can be realized by selling top grade logs for veneer than by cutting them into lumber.

Mr. Lane: Our grade yield data indicate that the larger grade 1 logs would be worth more for veneer than for lumber. We found that some of the larger mills were stock-piling their veneer quality logs and shipping them in carload lots. However, many of the operators, get such a small number of veneer logs that they can not afford to stock pile them and therefore usually manufacture them into lumber along with the rest of their sawlogs.

C. D. Dosker (Gamble Brothers): I feel sure that if the small sawmill operator would write to the veneer mills in his section he would find that in most instances he could realize more from his top logs if he sold them to a veneer mill rather than converting them into lumber.

Mr. X: You have indicated that the average circular mill could reduce daily "shut-down" time by 50 percent. What would this mean in terms of additional production and profit?

Mr. Lane: Reducing "shut-down" time by 50 percent will, for the average mill, reduce production costs $2.00 per thousand board feet or increase production about 1,000 board feet per day and profit almost $20.00 per day with the same labor cost.

Mr. Dosker: It is important to know the cause of the shut-down of the small mill. It may be log supply, or it may be breakdown of equipment. In most cases mills do not obtain their best production because of improper maintenance. Makeshift repairs can frequently prove costly in the long run. Small repairs, if made promptly, can save costly shut-downs over long periods of time resulting from neglect.

Mr. X: How do the log values you have shown for the dense hardwood species compare with yellow pine and the soft hardwoods?

Mr. Lane: Value curves have about the same trend. However, actual values for pine are 10 to 15 percent higher due to faster sawing time.

Mr. X: The diameter of average hardwood logs is 12 inches, what would be the net effect if the average were increased to 14 inches?

Mr. Lane: Production would be increased 15 percent, production costs would decrease $2.00 per thousand board feet, and the average value of lumber produced from the larger logs would be at least $3.00 more per thousand board feet.

Mr. X: To what extent do circular mills utilize their slabs, edgings and sawdust?

Mr. Lane: About 80 percent of the slabs and edgings are used for fuel; 20 percent are wasted because they are inaccessible and cannot be hauled economically. There is only a limited market for green sawdust. About 75 percent is wasted; 15 percent is used for boiler fuel; and 10 percent is used for animal bedding, soil improvement, sweeping compounds, etc.

Mr. Dosker: It has been my observation that very few small mills make any effort to utilize slabs and edgings in the production of small dimension stock. Most of the slabs and edgings are cut into fuel wood and sold in the vicinity of the mill.

Quality Control in Lumber Manufacture[1]

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Quality control and the effective use of quality-control charts offers a means of eliminating waste in lumber manufacture and improving sawmill operation, to the mutual benefit of sawmill operator and lumber buyer.

Introduction

LACK of quality control in the manufacture of lumber results in the production of a non-uniform product and the development of excessive waste. These effects are reflected in higher costs both to the producer and the consumer and are, therefore, to be avoided. Statistical quality control techniques can be readily adapted to the control of the quality of lumber both at the manufacturing and using levels.

The term "Quality Control" has been used with reference to the manufacture of wood products to mean a great many things. As Shewart[2] has pointed out the term quality to many people indicates the "goodness" of a thing. It is in this sense that the word quality is used in advertising when the term "quality product" or "quality merchandise" is applied to articles of commerce. Shewhart has described this concept of quality as the subjective viewpoint. Quality may also be defined objectively. The first definition given in Funk and Wagnalls dictionary for the word quality is, "That which makes a being or thing such as it is; essential property; a distinguishing element or characteristic". In this sense of the word a product has not one but many qualities. A piece of lumber has qualities of thickness, width, grade, condition of surface, and many others. For the purpose of discussing quality control as an industrial technique the subjective definition of quality as the goodness of a thing is not suitable. It is necessary to use the objective definition of quality as a set of characteristics.

Radford[3] states, "The term quality as applied to the products turned out by an industry, means the characteristic or group or combination of characteristics which distinguishes one article from another, or the goods of one manufacturer from those of his competitors, or one grade of product from a certain factory from another grade turned out by the same factory." In the manufacture of lumber the qualities of thickness, width, grade, etc., are usually specified in accepted grading rules, specifications, or other standards of the industry. If the product is to be considered satisfactory, these characteristics of the lumber must meet the accepted standards. It is the purpose of this paper to describe some techniques which can be used in the manufacture of lumber to effect control over these qualities of the manufactured product.

In the manufacture of lumber as in the manufacture of any other mass produced product it is impossible to precisely duplicate the individual articles in the same nominal group. Variation from article to article is expected and accepted. The causes for this variation from board to board in the same nominal group are infinite. Many of the causes are unknown and if they were all known, it would be undesirable to attempt to do anything about many of them. They are chance causes which are accepted as being normal to the production operation. While such chance causes of variation are accepted as being normal to a manufacturing process, it is expected that this variation will occur within limits and that it will be of such magnitude that the final product will have utility. The statistical quality control techniques developed originally by Shewhart and his colleagues at the Bell Telephone laboratories are valuable tools for evaluating a production process to determine what its natural variation is, for revealing assignable causes for excessive variation when they are present and for the identification of such assignable causes so that they can be eliminated.

"Quality" as Applied to Lumber

In the manufacture of lumber, thickness is one quality which must be controlled. Emphasis is most frequently placed on control of thickness to the end that excessively thin boards will be eliminated. Much lumber is surfaced to obtain its final dimensions. If the lumber is too thick it can be cut down in the planer to the proper dimension. If it is too thin, there isn't much that can be done in surfacing except

[1] A joint project of the Wood Products Laboratory, North Carolina State College and the North Carolina Department of Conservation and Development. The authors express their appreciation for the cooperation afforded by the Walton Lumber Company, Mebane, North Carolina, and the Cary Lumber Company, Durham, North Carolina, during the course of the investigations.

[2] Shewhart, W. A. Economic Control of Quality of Manufactured Product. Van Nostrand, New York, 1931.

[3] Radford, G. S. The Control of Quality in Manufacturing. Ronald Press—1922.

perhaps to surface it down to the next lower nominal dimension. A frequent comment of planing mill operators with reference to thick and thin lumber is, "We can take it off, but we can't put it on". Accordingly, emphasis in the control of thickness is likely to be on the elimination of thins. Actually there are equally compelling if not so obvious reasons for the elimination of excessively thick boards. Such boards overload surfacing equipment resulting frequently in slower operation, shorter machine life and excessive maintenance costs. Further the extra thickness represents unnecessary waste that is reflected in lower yields. Money is expended on this waste wood in the procurement of stumpage and the cost of transportation and handling from the forest through the sawmill to the planing mill with no compensating value at the end of the line. It is important, therefore, in the manufacture of lumber to control the thickness as well as possible through the elimination of chance causes for excessively thick and thin lumber.

The same factors which make it desirable to control the thickness of lumber are applicable to control of width.

It was the objective of this study to evaluate some statistical quality control techniques as applied to the control of thickness and width of rough lumber. The research was conducted on small portable sawmills of the type that produce a substantial part of the lumber manufactured in Eastern United States. The same techniques may be applied in control of lumber quality at larger mills.

Application of Charts

Since an excessive amount of thick and thin lumber is objectionable at planing mills and concentration yards handling the output of small sawmills, it would be advantageous for many of these installations to exercise some form of quality control over their suppliers. A convenient tool for the exercise of such control is the chart for fraction defective. Fig. 1 illustrates the application of such a chart to the receiving reports on shipments of hardwood lumber coming in to a concentration yard from a group of small sawmills. These receiving reports indicated only the thins and not the excessively thick boards. The chart shows lack of control, with out-of-control points falling beyond the upper and lower control limits. The points falling beyond the upper control limits indicate an excessive number of thin boards in a particular shipment. It will be noted that out of 10 of the points falling above the upper control limit, 7 represent shipments from suppliers A and B. The action indicated to effect control is to work with operators A and B to obtain a reduction in the percentage of thin boards or to eliminate them as suppliers. The same action in perhaps a less vigorous manner would be suggested for the operators with occasional shipments out of control.

The out of control points on the low side suggest several possible causes. The appropriate one should be determined by investigation. It may just be a lucky accident in which case no action is necessary. The low points may result because the operator is sawing for a higher average board thickness than his competitors to avoid rejection of thins. If this is the case it is certainly disadvantageous to the operator and for the reasons previously given may be equally undesirable from the customer's viewpoint. In this instance some action to improve the general control of thickness by the sawmill operator at a lower thickness level might be desirable for the customer even if it resulted in a slight increase in the percentage of thins. Another possible cause for the low points is an inspection error on the part of the grader. Failure of the grader to recognize and throw out thins at receiving inspection could produce this indication on the chart. Finally the low points might result from improved operation. The suppliers involved may have better control at the sawmill or more careful shipping inspection. If this is the case and other suppliers could be persuaded to adopt the same procedures a general improvement in the quality of all shipments might be possible. This would be reflected in the control chart in narrower control limits and a lower level of percent defective.

Control of grade was not one of the subjects investigated during this study, since the concentration yards cooperating were taking mill run material. Where lumber is bought on grade, similar P charts could be used to maintain control of grade. Because the cooperating lumber yards were buying mill run material all incoming lumber was graded as it arrived, hence a percent-defective chart was easy to keep and inexpensive to maintain since the necessary information could be obtained from the grade reports. Where lumber is bought on grade the quality check on dimension and grade could be accomplished by sampling each shipment. The same type of P chart could be used to analyze such samples. The single, double and sequential methods of acceptance sampling would also be adaptable to receiving inspection of lumber where a sample check only was made and these methods would be likely to be less expensive. The same techniques could also be used to control the quality of incoming lumber shipments with reference to widths.

As previously indicated lack of control in P charts used at receiving inspection frequently points to the need for better control of the manufacturing operation of the sawmill. Statistical quality control methods may be readily adapted[4] to control of thickness and width at the head saw and edger. For control of these operations the control chart for variables ($\bar{X}$ and R chart) is more sensitive and more productive of information than is the P chart.

[4] Bethel, J. S., Barefoot, A. C., and Stecher, D. A.—Quality Control, a Study in Small Sawmill Operations. Southern Lumber Journal. Dec. 1950.

Figs. 2 and 3 illustrate two control charts for thickness of 4/4 lumber produced by two sawmills studied. For the purpose of this quality control study a sub-group consisted of four thickness measurements made on a board. The measurements were made on the board as illustrated in Fig. 4. The two mills studied were made by the same manufacturer and were operating within a mile of each other on comparable timber and were shipping to the same concentration yard. The planing mill at the concentration yard specified that the green thickness of 4/4 lumber be 1⅛ inches and lumber with a green thickness less than 1 inch was culled. Mill B (Fig. 3) shows serious lack of control while Mill A (Fig. 2) shows reasonably good control although too many points fall outside the control limits to justify describing the operation as being in control. It will be noted that the control limits for average board thickness had about the same spread for both mills indicating that the sawmills had about the same capabilities for the production of uniform lumber. The average board thickness for Mill A was 37/32 inch while that for Mill B was in excess of 40/32 inch. It was necessary for Mill B to produce an average board almost ⅛ inch thicker than that produced by Mill A to meet the same minimum thickness requirement of the planing mill. For the period of the study Mill B delivered approximately 7½ percent more actual wood to the planing mill to get the same nominal scale than did Mill A. This extra 7½ percent represents extra planing mill waste and contributes nothing to the advantage of either the sawmill or the planing mill. In this case the lack of control at Mill B was due largely to careless setting by the sawyer.

Fig. 5 represents a control chart for variables which illustrates the way in which the application of statistical quality control methods can bring about an improvement in quality control. At the start of the study the mill was badly out of control as far as board thickness was concerned. The average board thickness was large to permit thin boards to satisfy the minimum planing mill thickness requirements. The spread between upper and lower control limits was wide indicating a basic inaccuracy in the sawmill as a lumber manufacturing machine. During the 17-day period of the study the operator made several changes in his equipment to correct defects revealed by the control chart with a resulting improvement in both yield and uniformity in lumber thickness.

Causes for Loss of Quality

One of the results of the study of the eleven mills investigated during this project was to reveal some of the major causes for lack of control of board thickness at small sawmills. These causes can be separated into two groups; those resulting from equipment defects and those resulting from operational mistakes.

Equipment Defects

Among the equipment defects, that of improper mill set-up was most frequently encountered. This defect stems very largely from the portable character of most small sawmills. They are designed to be portable and are frequently set up to be operated for a few weeks or months and then moved. The operators are understandably reluctant to expend any more than a minimum of time and money to set them up for operation. Accordingly many mills are not properly aligned and leveled when they are set up. Frequently they are placed on inadequate foundations and as a result they settle in use and get seriously out of level and alignment. One of the major improvements made in the mill represented by the chart in Fig. 5 was to straighten the track and re-align the mill.

A second equipment defect that resulted in poor control of board thickness was inadequate power. This is not necessarily the result of operating with a power unit that is too small in horsepower, although that is sometimes the cause. Frequently the mills with large diesel power units revealed inadequate power at the saw as evidenced by an excessive rpm. drop in the cut. There were several reasons for this apparent lack of sufficient power where large sized power units were in use. The most common fault was that the operators were trying to maintain high production rates by operating with a very high rate of feed and high mandrel rpm. The same power units would operate the sawmills satisfactorily with lower feed rates and saw speeds. All of the evidence collected during this study indicated that a high rate of production could be maintained at a lower saw speed. When the saw was running at too high a speed, high rpm. drops in the cut developed. The lumber was non-uniform in thickness since, at a lower rpm,, the saw dished and wobbled. Other causes of inadequate power at the head saw when power units were apparently large enough to do the job were: improper saw maintenance, inefficient power take off and transfer belts, poor maintenance and operation of such auxiliary equipment as edgers, cut-off saws, slab saws, and sawdust and slab conveyors. Some large power units were delivering only a portion of their rated horsepower because of age and improper maintenance and operation. The control chart illustrated in Fig. 6 shows a substantial number of boards out of control which were traced to excessive rpm. drops in the cut.

Another equipment defect which caused lack of control was improper lead in the saw. Some operators did not know how to properly set lead by adjustment of the saw mandrel. Others were just careless about setting it. Several operators were filing lead into the saw and obtaining non-uniform lumber as a result.

Poor saw maintenance was also found to be an important cause of miscuts. This involved operation of dull saws, improper sharpening and swaging,

warped saws and operation of saws at speeds other than the one for which the saw was tensioned. Fig. 7 shows a control chart for a sawmill cutting hardwood. The sudden changes in the spread of control limits in the center of the chart occurred when bits which were dull and inadequately swaged were replaced by a new set of bits.

Another equipment defect that resulted in miscut lumber was improper carriage alignment. In head block type mills this resulted when the knees were not lined up parallel to the cutting line. In log beam type mills it may result from warped or sprung beams. This defect resulted in a dog board that was wedge shaped from end to end and out of control. Another form of carriage mis-alignment that contributed to lack of control was that resulting from end play in the carriage trucks. This defect resulted in miscut boards that were indiscriminately thick and thin throughout their length.

Operational Mistakes

The most common operational mistake that caused lack of control was that of careless setting. Some sawyers did not pull to a pin on the set works quadrant or use a sawing guide board as an aid to setting, although all of the mills studied were equipped with at least one of these sawing guides and most frequently they had both. The lack of control illustrated in the control chart in Fig. 3 was traced to this cause. The sawyer at this mill was setting 4/4 lumber without the use of a pin and without reference to a guide board. As a result, while the range in thickness from one part of a board to another was comparable to that obtained with mills operated in control, the variation in thickness from board to board was great and exhibited lack of control. In those instances where the sawyer was pulling to a pin, lack of control sometimes resulted. If he failed to pull all the way to a pin a thin board was manufactured and if he pulled too hard the slack in the rack and pinion allowed an excessively thick board to be cut. Where care was used in setting, either the use of a pin or a sawing guide board proved satisfactory.

Another common operational error was that of miscalculation. When sawyers didn't take the time to calculate their cuttings prior to starting on the last two sides[5] of the log the dog board was frequently either too thick or too thin. Sometimes the sawyer would recognize his problem after getting into the cant and then multiply it by spreading his error over the last three or four boards instead of allowing it to appear only in the dog board. An experienced sawyer can make the necessary calculations in a matter of seconds and those sawyers that were calculating their cuts were producing as much lumber as those that were not.

An operational fault that was frequently observed was inadequate dogging. All of the mills studied were equipped with at least three dogs and the best quality control was obtained where three were used. Many sawyers use only the front dog when the log is in the round. This provides inadequate support for the log during sawing and the movement of the log on the carriage results in thick and thin lumber. Since all of the mills studied had sufficient personnel on the deck to handle the other dogs this defect was one that could easily be corrected.

There are two operations which must be controlled to obtain satisfactory quality control of the widths of boards produced by a sawmill. The width of the boards cut from a squared cant is determined in the sawing operation on the head saw when the cant is squared. The width of boards produced from the round log is a function of the edging operation. This operation may be accomplished with the head saw by stacking the boards on the carriage or it may be accomplished through the use of a gang edger. The causes for lack of control of the width of boards sawed from squared cants are the same as those for lack of control in thickness. In studying quality control of thickness it was observed that the dog board was the one most likely to be out of control. This is true because errors in sawing boards from a log tend to be accumulated in reverse in the dog board. For example, if the majority of boards cut from sides two and four of a log were slightly thinner at the ends than in the center, the dog board would be substantially thicker at the ends than in the center. If the same thing occurs in sawing sides one and three the width of the cant will have the same accumulated errors that would appear in the dog board when cutting sides two and four. These accumulated mistakes will then be represented by lack of control in the width of the boards from the squared cant. It is obvious then that good quality control of thickness at the head saw will result in good quality control of widths of boards sawed from squared cants and poor quality control in thickness will also be reflected in poor quality control in widths of boards from the squared cants.

Many of the causes of poor control of thickness will also result in poor control of widths of boards edged on the head saw. In addition poor control of widths in this operation can result from careless stacking of the boards on the carriage.

Quality as Influenced by the Gang Edger

Quality control of the widths of boards sized on the gang edger involves a set of problems different from those encountered when edging on the head saw. In studying the problem of quality control at the edger $\bar{X}$ and R charts were used which were similar to those used in controlling thickness. A sub-group consisted of four measurements of the width of a board coming from the edger. The meas-

[5] Sawing order is described using Southern Pine Inspection Bureau nomenclature. Side one is the first side of a log sawn. Side 2 is the first side of the log sawn adjacent to side 1. Side 3 is the side opposite side 1. Side 4 is the side opposite side 2. Cahal, R. R. Sawmilling Practices that Pay. Southern Pine Inspection Bureau, 1947.

urements were taken at the same points as were the thickness measurements at intervals of approximately 1/5 the length of the board. Fig. 8 illustrates a control chart for the widths of boards from an edger in which reasonably good control is being obtained.

Fig. 9 shows a control chart for an edger operation that tends to be deceptive. It shows apparently perfect control but the control limits are very wide apart as compared to those shown in Fig. 8. An examination of the data (Fig. 10) upon which this chart is based will reveal the cause. It will be noted that the boards get progressively thinner from the front to the back in almost every case. This within sub-group pattern yields an abnormally high mean range resulting in the wide spread in control limits and apparent good control. This type of chart can result from an operation in which the saws are bent or warped, saw collars are out of alignment or not true, saws are dull or improperly sharpened, guide bar is not parallel to the saws, feed rolls are out of alignment, or the saw mandrel is not true.

Fig. 11 illustrates another cause of lack of control in widths. In this instance the control limits are very close together but a large number of the points fall outside these limits. This indicates that the boards are uniform in width from one part of a board to another but the width varies excessively from board to board. This condition can be due to one or more of the causes given for the wide control limits of the chart illustrated in Fig. 9, if they happen to be operating intermittently. It can also be due to careless feeding on the part of the edger operator. When the condition is as extreme as it is in the chart illustrated in Fig. 11 it is likely to be due to some defect in the edger which results in its failure to set the same width each time the operator moved the lever controlling the moving saw to a particular setting. The control bar usually rides in groove between the saw collar and a movable outside collar. If the width of this groove becomes excessive either through wear or slippage of the outside collar, the play of the control bar in the groove will be sufficient to preclude satisfactory repetition of settings. When this condition exists it may result in two distinct populations of widths for the same nominal width, depending upon where the movable saw was prior to setting. For example, in edging 8-inch boards the moving saw may assume one position on the mandrel when it is moved in from a previous setting of 10 inches or 12 inches and another position when it is moved out from 4 inches or 6 inches. The solution is, of course, to readjust the collars or to replace worn parts.

Conclusions

The results of this study indicate that statistical quality control techniques can be effectively utilized to improve quality control in the manufacture of lumber at small sawmills. They suggest that the same methods might be applicable to large permanent sawmills. Lack of quality control in the manufacture of lumber results in excessive waste of wood both at the sawmill and in later use, with a corresponding higher cost to the mill operator and to the user. Lack of quality control also results in an unpredictable product thus creating problems for both producer and user.

Discussion

Charles Latimer (Nickey Brothers, Inc.): Doesn't Dr. Bethel agree that no saving occurs unless logs are at least a certain diameter; and what is this minimum?

Dr. Bethel: Yes, I believe the minimum is about 14 or 15 inches.

Dean B. Richards (The Lilly Company): Just a remark in regard to the loss in poor manufacture and wide kerfs. Many people mistakenly claim that if you save $\frac{1}{16}$ inch on each board, you have to cut 16 one-inch boards from a log before you save enough wood to make another board. Actually if your dog board was going to come out $\frac{3}{4}$ inch, it would only be necessary to save $\frac{1}{4}$ inch to make the dog board a salable one-inch board. On the average, your production of boards will probably increase by about the percent you save on each cut.

Dr. Bethel: This may be partially true as you consider that it is necessary to save enough in thickness to yield an additional board. Actually, there is an increase in yield due to greater board width even where the increase in thickness does not yield an extra board. If you are to make up the extra board entirely from savings from the boards cut, the log would probably have to be 14 or 15 inches in diameter.

Walton R. Smith (Walton Lumber Company, Inc.): From my experience with small sawmills cutting poplar lumber, I am inclined to believe that the thickness of the kerf has little effect on the yield. The greatest losses are due to miscut lumber: thick at ends and thin in middle or vice versa, wedge shaped boards, boards too thin to make the grade, and boards too thick. When we can get the small sawmill operator to correct these gross misadjustments, it will be worth while to concern ourselves about the thickness of the kerf. Regarding the minimum diameter, we recommend to our suppliers of poplar lumber that they do not cut trees under 14 inches in diameter except in special instances. Our recommendation is seldom followed, however.

A. Frederic Wetherill (Henry Disston & Sons, Inc.): How many people are necessary to set up X and R Charts?

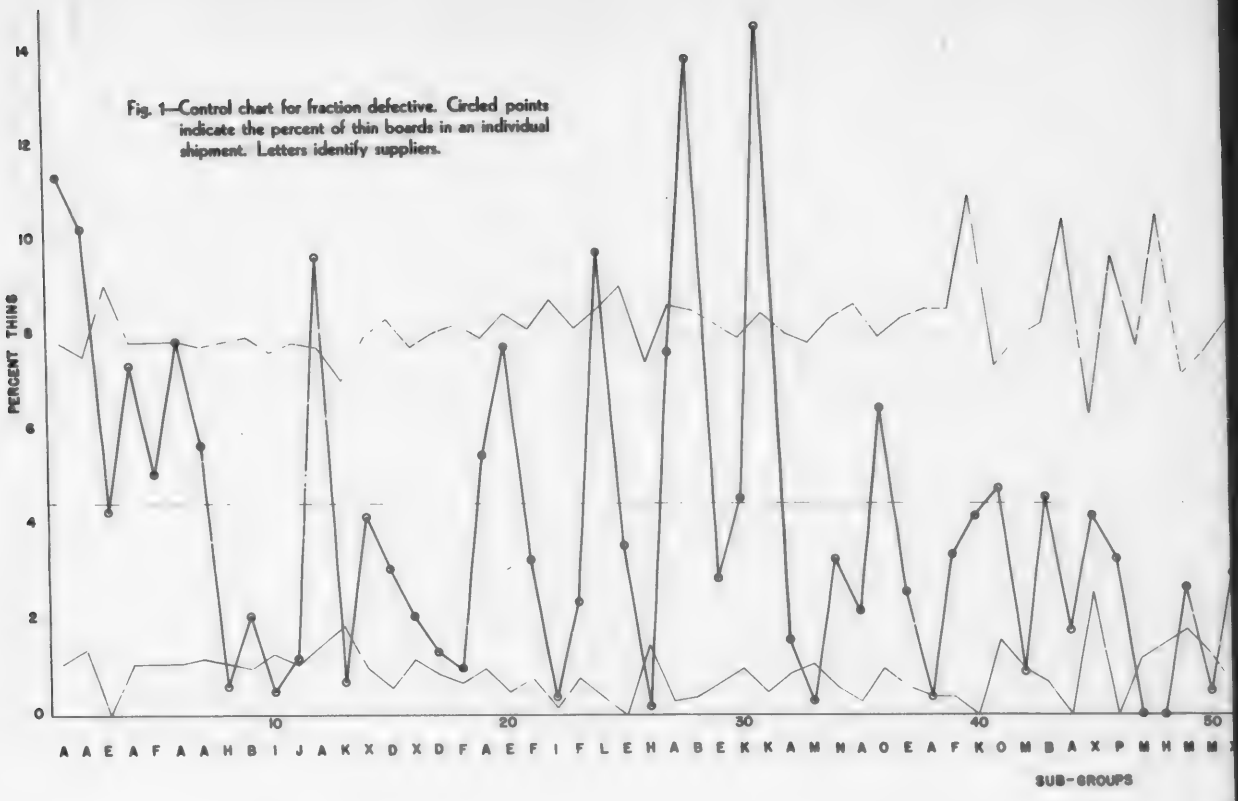


Fig. 1—Control chart for fraction defective. Circled points indicate the percent of thin boards in an individual shipment. Letters identify suppliers.

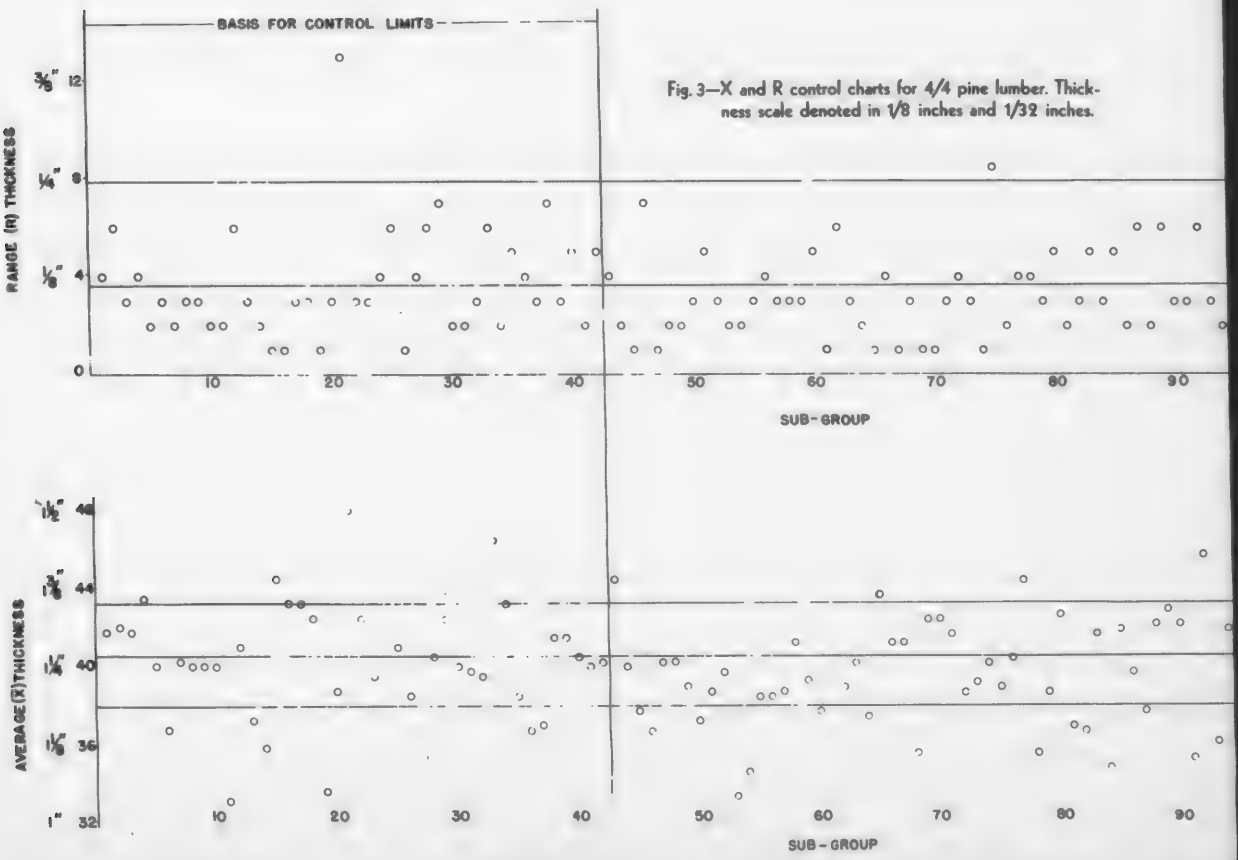
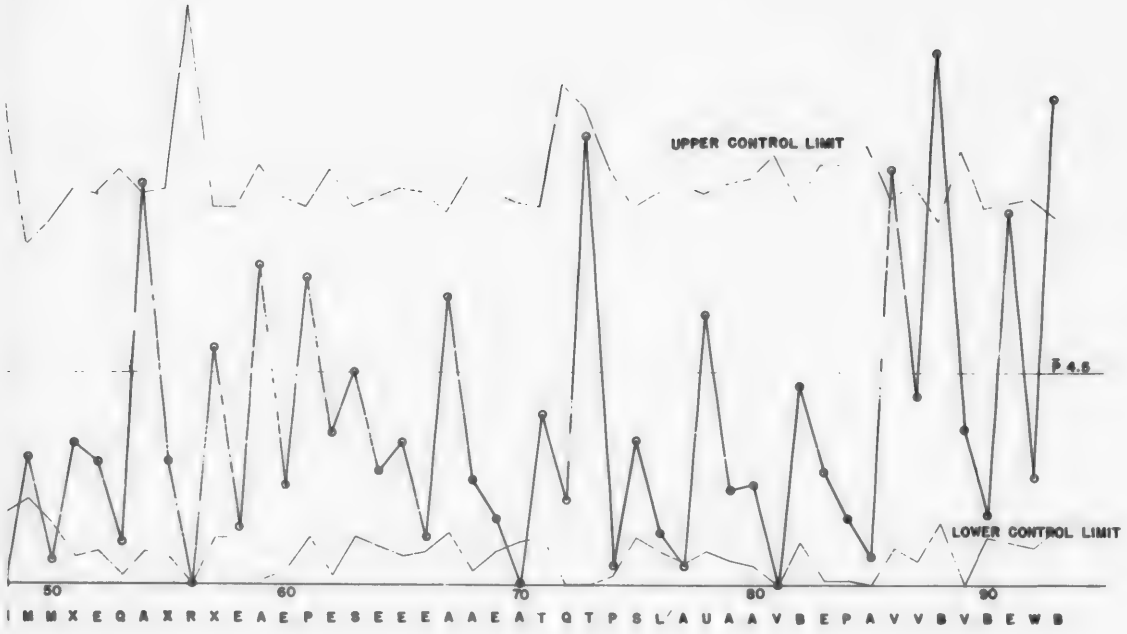
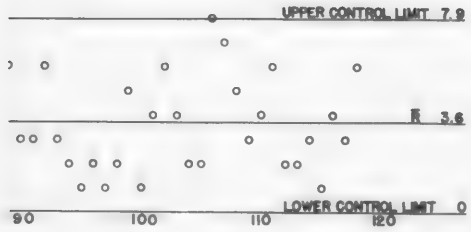
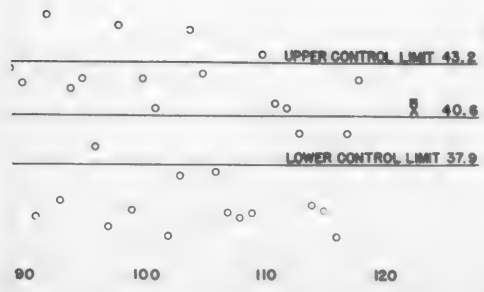


Fig. 3—X and R control charts for 4/4 pine lumber. Thickness scale denoted in 1/8 inches and 1/32 inches.







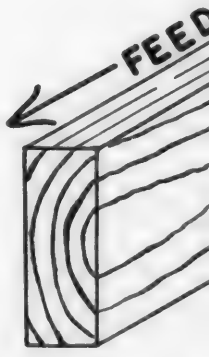
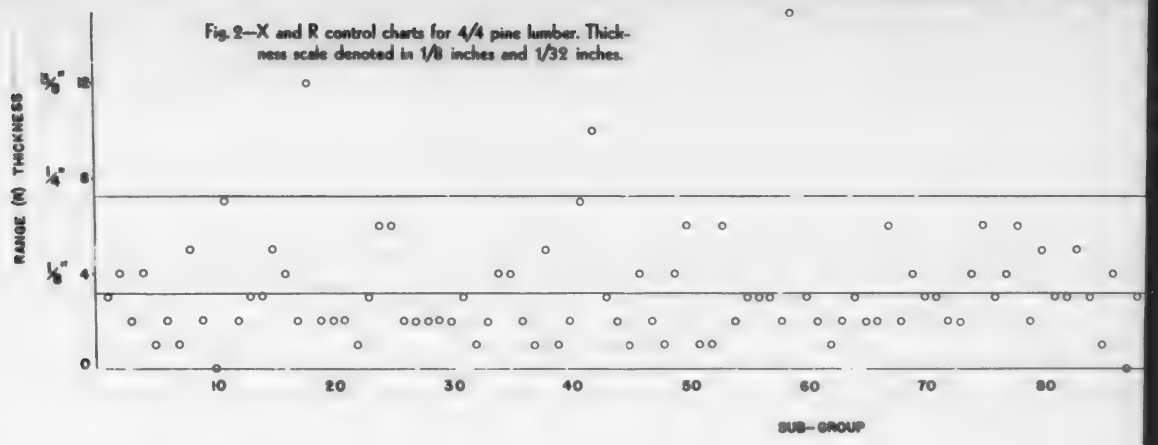
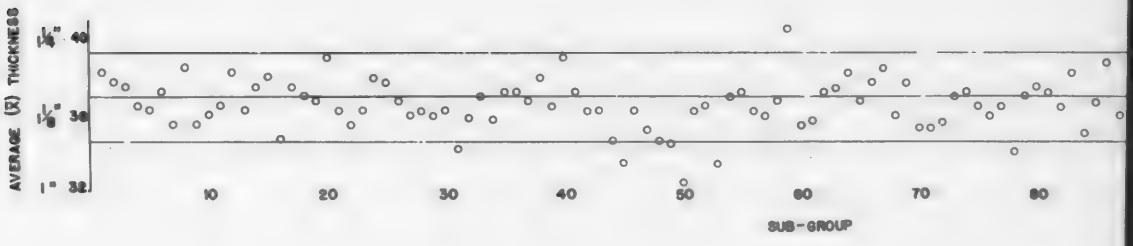
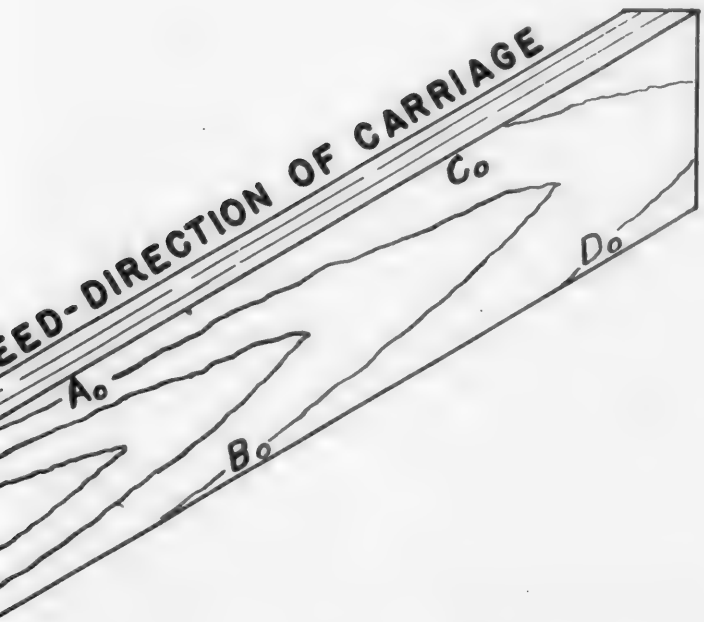


Fig. 4—Sketch showing the
measured on each
on each board cons

Fig. 2—X and R control charts for 4/4 pine lumber. Thickness scale denoted in 1/8 inches and 1/32 inches.

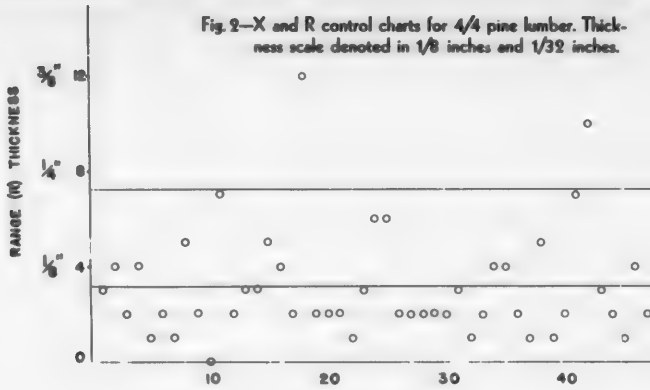


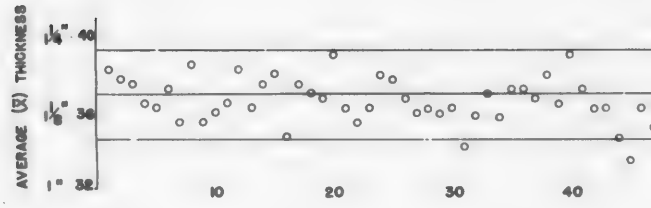


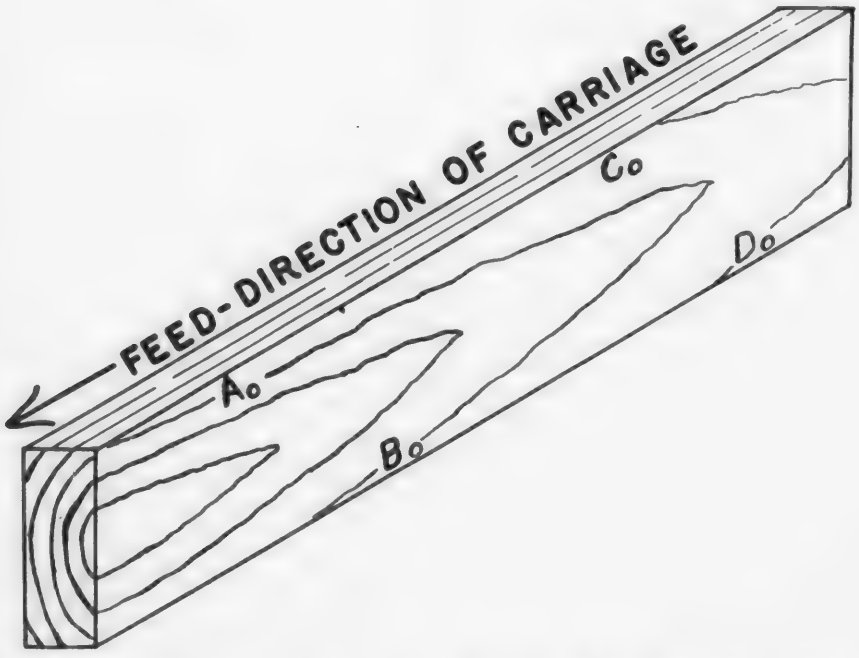


the points at which thickness was
ch board. The four measurements
onstitute a sub-group.

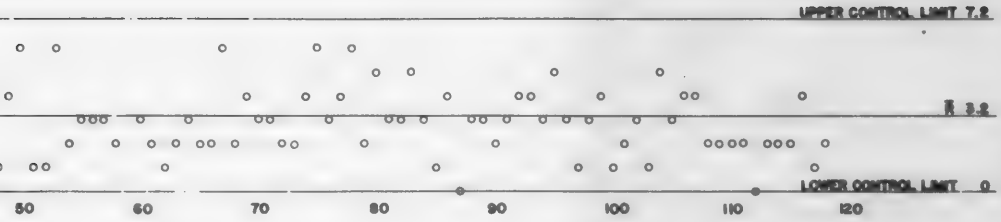
Fig. 2—X and R control charts for 4/4 pine lumber. Thickness scale denoted in 1/8 inches and 1/32 inches.







showing the points at which thickness was
ed on each board. The four measurements
h board constitute a sub-group.


UPPER CONTROL LIMIT 7.2
$\bar{\bar{X}}$ 3.2
LOWER CONTROL LIMIT 0
50
60
70
80
90
100
110
120
SUB-GROUP

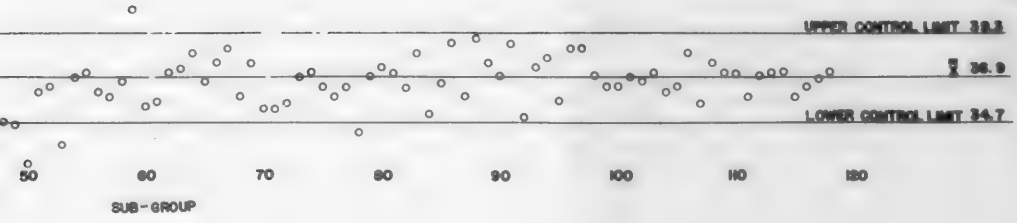
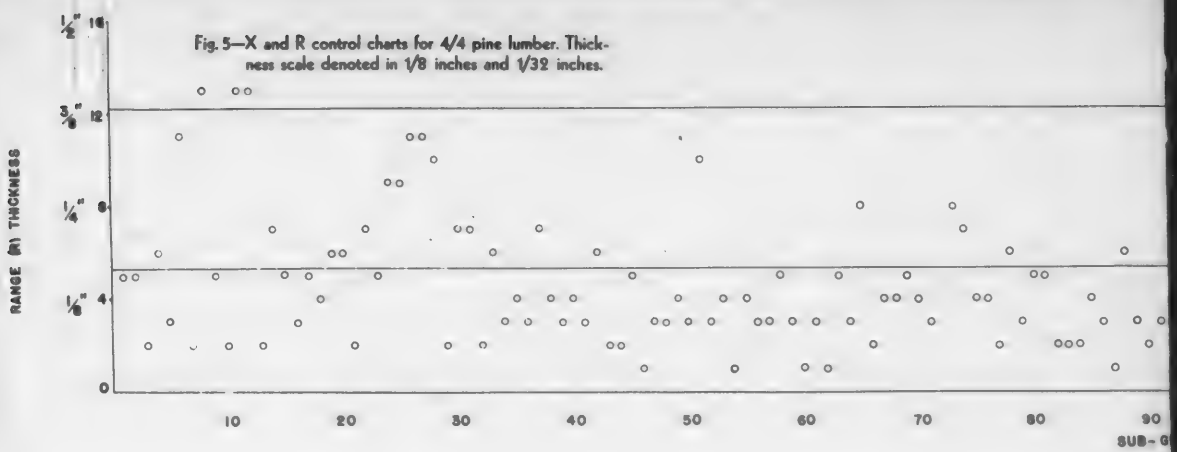

UPPER CONTROL LIMIT 38.3
$\bar{\bar{X}}$ 36.9
LOWER CONTROL LIMIT 34.7
50
60
70
80
90
100
110
120
SUB-GROUP

Fig. 5—X and R control charts for 4/4 pine lumber. Thickness scale denoted in 1/8 inches and 1/32 inches.



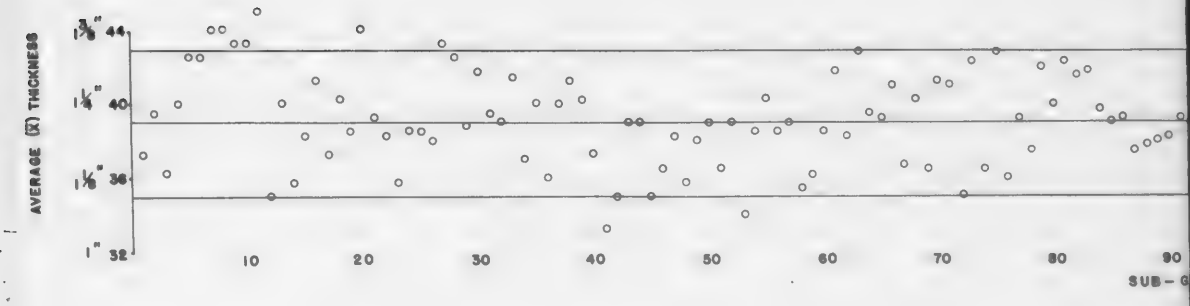
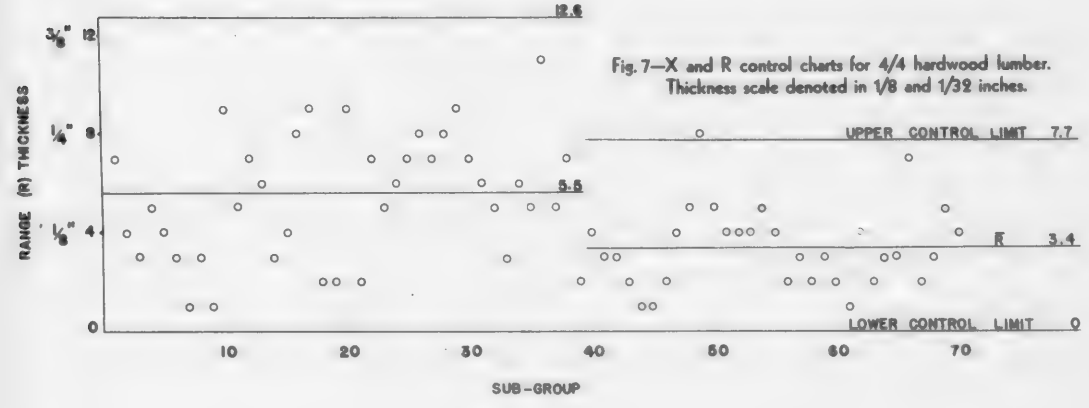
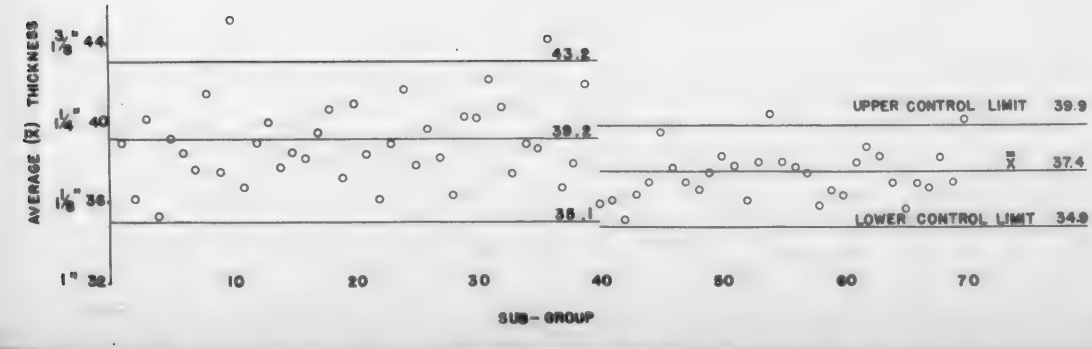
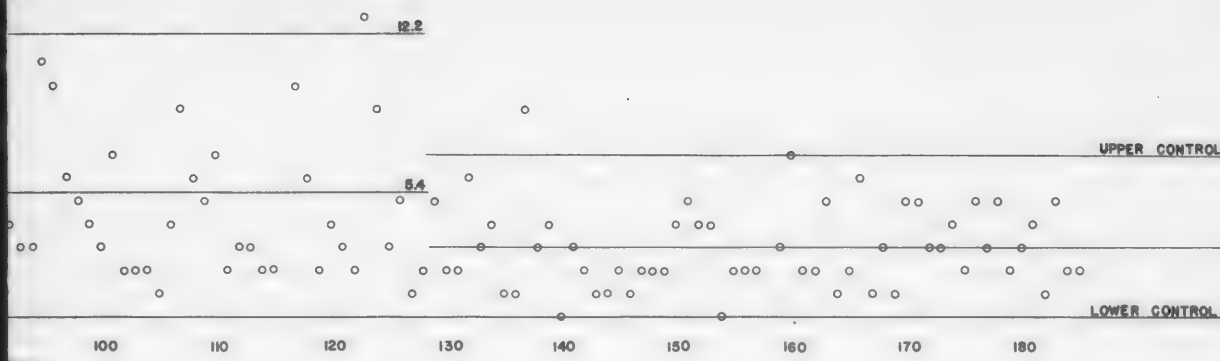


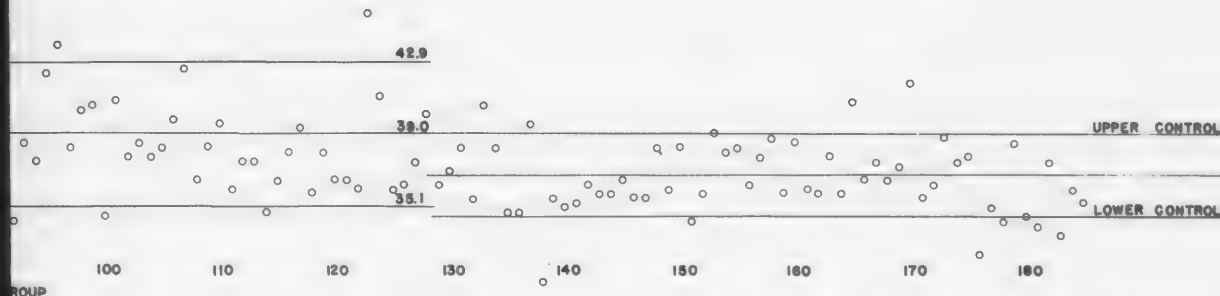
Fig. 7—X and R control charts for 4/4 hardwood lumber. Thickness scale denoted in 1/8 and 1/32 inches.







ROUP



ROUP

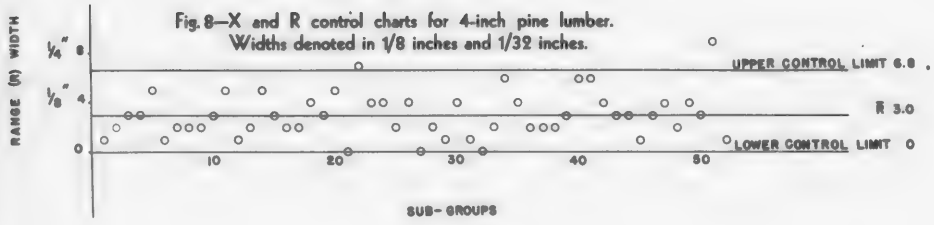
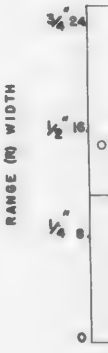
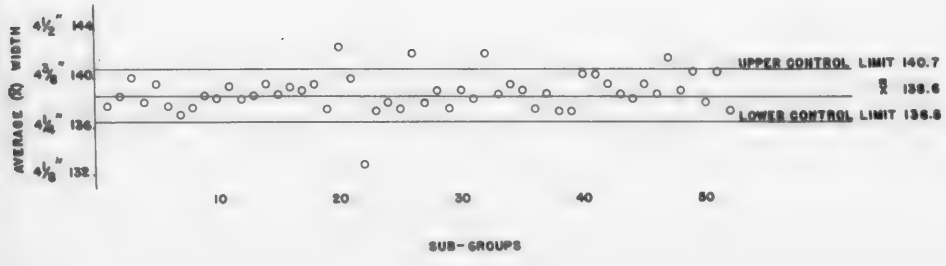


Fig. 8—X and R control charts for 4-inch pine lumber.
Widths denoted in 1/8 inches and 1/32 inches.



RANGE (R) WIDTH



AVERAGE (X̄) WIDTH

CONTROL LIMIT 7.0

$\bar{R}$ 3.1

CONTROL LIMIT 0

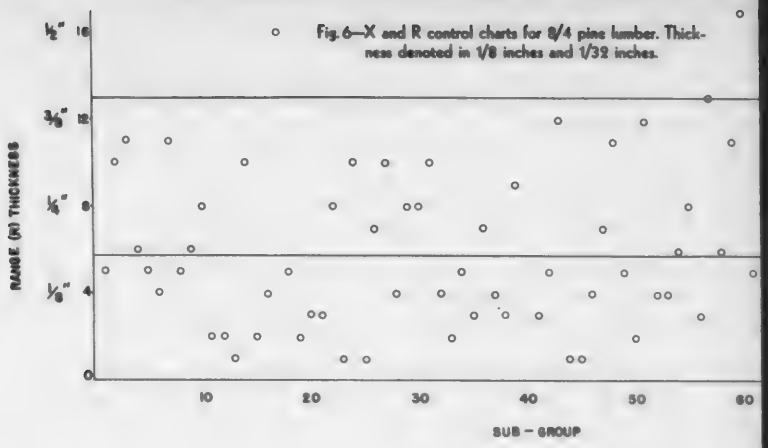
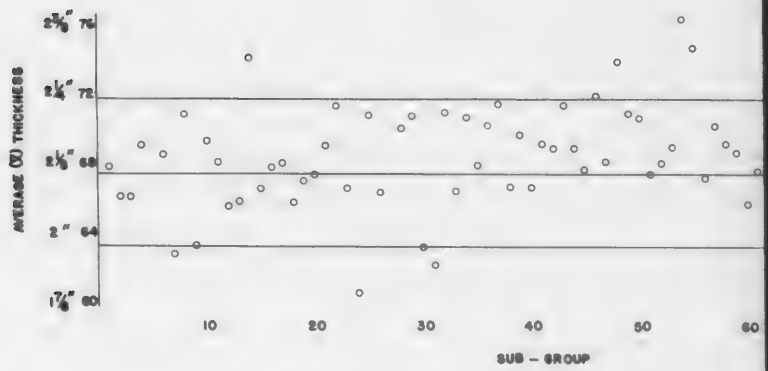


Fig. 6—X and R control charts for 8/4 pine lumber. Thickness denoted in 1/8 inches and 1/32 inches.

CONTROL LIMIT 39.0

$\bar{\bar{X}}$ 36.8

CONTROL LIMIT 34.6



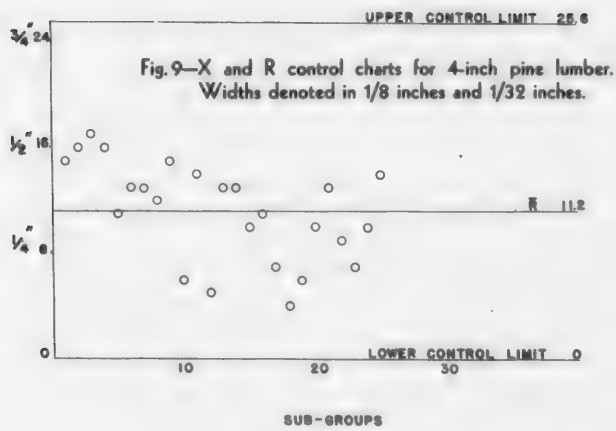
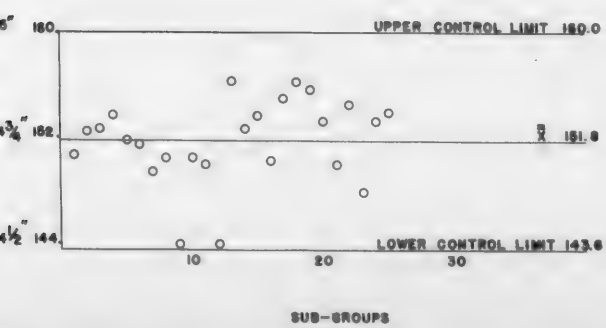


Fig. 9—X and R control charts for 4-inch pine lumber. Widths denoted in 1/8 inches and 1/32 inches.



RECORD SHEET FOR $\bar{X}$ AND R CHAR

Material Southern Yellow Pine

Characteristic Measured Width

Unit of Measurement 1/32"

Sub-Group	A	B	C	D
1	142	148	157	156
2	142	152	158	158
3	141	154	158	158
4	144	154	157	160
5	144	154	155	154
6	142	154	155	155
7	141	148	154	154
8	143	150	154	155
9	142	150	149	135
10	142	150	156	142
11	142	147	155	156
12	142	147	146	141
13	149	156	158	162
14	144	155	155	157
15	146	155	156	156
16	143	150	154	154
17	150	156	157	157
18	154	156	158	157
19	152	156	157	158
20	147	152	157	157
21	143	147	154	156
22	148	156	157	157
23	143	149	150	150
24	147	153	157	156
25	144	155	159	158

Total $\bar{X}$

$\bar{X}$

U.C.L.$\bar{X}$. $= \bar{\bar{X}} + A_2\bar{R}$

$= 151.78 + (.73)(11.20)$

$= 151.78 + 8.18$

$= 159.96$

L.C.L.$\bar{X}$. $= 151.78 - 8.18$

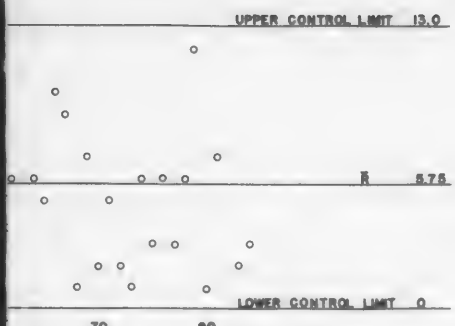
143.60

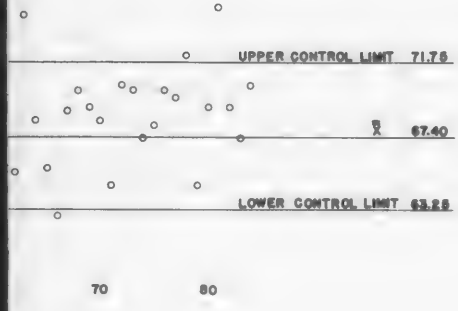
U.C.L.R. $= (D_4)(\bar{R})$

$= (2.282)(11.2)$

$= 25.56$

Fig. 10—Record sheet with data on whi





T

Mill A

Date 7/19/50

Recorder Stecher

Mean	R
150 75	15
152 50	16
152 75	17
153 75	16
151 75	11
151.50	13
149 50	13
150 50	12
144 00	15
150 50	6
150 00	14
144 00	5
156 25	13
152 75	13
153 75	10
150 25	11
155.00	7
156 25	4
155 75	6
153 25	10
150 00	13
154.50	9
148 00	7
153 25	10
154.00	14

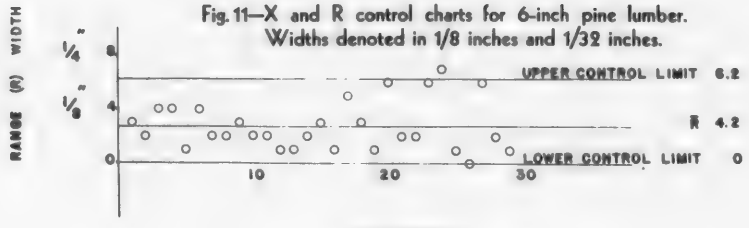
= 3794 50

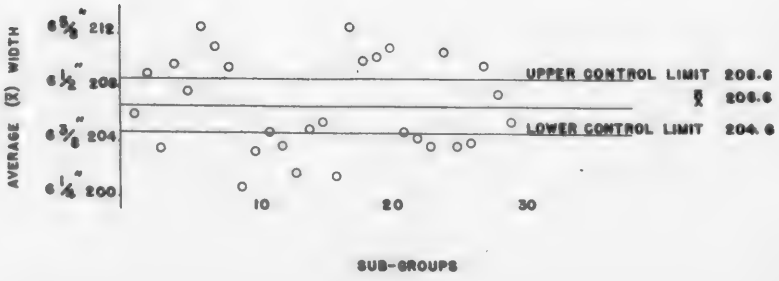
Total R = 280

= 151 78

R̄ = 11.20

Fig. 11—X and R control charts for 6-inch pine lumber. Widths denoted in 1/8 inches and 1/32 inches.





ch Fig. 9 was based.

Dr. Bethel: The number required depends upon how much you are trying to do. Much of our research work was accomplished with one man at the mill and this proved very satisfactory. If you wish to collect a lot of data in a short period of time, two men could work more efficiently. If a chart was being maintained as a regular control measure, infrequent measurements are all that would be required. A sample taken perhaps once or twice a day should suffice after control is established.

J. Howard Schmidt (Pennsylvania State College): How much variation would you find in widths?

Dr. Bethel: A good edging operation should be capable of dimensioning boards to width within a tolerance of + or — $\frac{1}{16}$ inch. The control chart for widths is of course only applicable to softwoods since hardwoods are manufactured to random widths.

Ted C. Weill (Michigan State College): Is it usual practice to cut 4/4 boards $1\frac{1}{8}$ inches green?

Dr. Bethel: This was the practice at all of the mills studied and is a general practice in the Southeast.

B. C. Williams (Norfolk Naval Shipyards): Is overcutting a practice of particular mills or is it due to slovenliness of the operator?

Dr. Bethel: Cutting boards too thick is a practice followed by mills which have poor control, to insure that they have few thins. It is a wasteful and undesirable method of compensating for lack of good quality control.

Mr. Schmidt: Do you feel that your studies indicate that the semi-stationary mills can work to as narrow control limits as the stationary mills?

Dr. Bethel: Yes, our studies indicated that semi-stationary or portable mills can produce lumber of comparable accuracy to that of stationary mills if the mills are set up properly, maintained properly and correctly operated.

Mr. Schmidt: Your study has been concerned with size rather than grade. Don't you think that it is more important to emphasize improvement in sawing for grade?

Dr. Bethel: We consider that it is important to improve the quality of lumber produced in small saw mills both from a standpoint of dimension and grade. This particular study was confined to an investigation of the application of quality control techniques to dimension. It is planned to continue the study to develop statistical quality control methods which can be applied to quality of grade.

The Use of Gangsaws in the Manufacture of Southern Pine Lumber

E. E. DARGAN, *Dargan Lumber Manufacturing Company, Conway, South Carolina*

The operation of a round log gangsaw on southern pine is described together with a statistical analysis of the log input and lumber output of the mill.

Introduction

THIS paper necessarily will deal with our operation at Conway, South Carolina, as the writer has only scant information on other gangsaw installations. Since there are only about eight or nine round-log gangs in the South it may be as well that the subject is handled in this manner.

Equipment

A description of the equipment used follows:

1. A derrick with sufficient capacity is used to unload logs from trucks upon their arrival at the mill yard. The load of logs remains in the unloading sling for convenience in further handling.

2. A smaller derrick nearby is used for assorting the logs into various size and grade groups. Logs are divided into three or four groups. This grouping varies with fluctuations in the lumber market, both as to the demand for certain sizes and price changes. For instance, on occasion 4/4, 5/4 or 6/4 material is sawed from either the small or the larger logs. Segregation of the logs by size or grade is of great importance, partially overcoming the objection to gangsaws for the reason that the sawing is not as flexible as in other types of mills. Sorting is also important in that the overhang of the saws, which governs the speed, can be set according to the size group to be cut. Of course, at least a four-hour run should be made on each size. Another factor in favor of sorting the logs is that a choice should be made as to whether the tip or the butt end should be run through first. There is considerable difference of opinion as to which is correct. The demonstrator sent by the factory to our installation advised that small ends face the saw due to the fact that in that way there would be a gradual increase of pressure on the hydraulic system for holding the log. However, our men, being inexperienced in gangsawing, tried placing the butts foremost and found, in their opinion, that this was to be preferred, the reason being that the larger end of the log would serve to push the short slabs from the preceding log through; whereas, if the small end was fed first, much time was often lost in getting short slabs on through the sash. After watching our operation the demonstrator was inclined to agree that our idea was the best.

3. After the logs are grouped, they are placed on a live log deck and brought to the loading point for the carriage. When cants are to be sawn, which in our case is unusual, they are handled in the same manner.

4. The logs are then rolled onto the carriage which consists of two parts linked by cable. Each portion of the carriage has four wheels. Chains travel in both directions between the carriage tracks, carrying the carriage forward or backward. This is controlled by the sawyer or carriage rider by use of pedal-operated clutches. The log is held between two points on the rear part of the carriage while resting on the front section. Alinement, of course, is very important and can be adjusted by the sawyer as the log is rolled on and moves toward the saw. Our experience has been that an automatic flycasting reel, which rewinds as the carriage moves forward, and unwinds as the carriage moves backward, makes a very helpful device for getting the logs properly alined. Logs usually can be kept continuously in the saw if they are released when they are about halfway through, thus emptying the carriage for the next log.

5. The gang mill itself, is the Swedish type Sash Gang with a 24-inch by 24-inch opening. This entire space can be filled with saws, the number of course, being determined by the spacing desired. Proper spacers are inserted and saws tightened. We make use of the can-type tighteners which we believe are superior to the wedge-type. Pressure for the feed rolls, which carry the log through the sash, is supplied by a hydraulic pump. The rolls are powered by a chain drive. This saw differs from the oscillating type gang in that the sash travels straight up and down at a high rate of speed. The saws are set at an angle, with the cutting done on the down stroke and is then returned through the space made on the down stroke. Too rapid a feed will cause the back of the teeth to strike the log and have a vibrating or chattering effect. The use of large ball bearings throughout the machine, with a pin bearing on the crank driving the saws, allows fairly high

speed although our experience has been that the speed recommended by the manufacturer is too high. The use of circulating water in jackets surrounding the slides is also a considerable factor in obtaining speeds up to 340 strokes per minute. Perhaps the density of southern pine accounts for our failure to find speeds up to 375 strokes per minute practical. Our machine is equipped with six rolls instead of the usual four. At the infeed and outfeed ends, we have two rolls on the bottom and one above, placed about halfway between the lower rolls. This helps to hold the logs steady and increases the average speed of cut. Another device which can be added to the saw to promote smoother operation is an inside support plate which can be placed between the rolls and about one-eighth inch from the saws. This serves in a manner similar to the action of a chip-breaker on a planer and will eliminate much vibration.

6. After the log emerges from the outfeed end of the saw through the set of guides or splitters, it is carried by a live roll case to a tilting device opposite the edger. The sawn log is then dropped to a conveyor which carries it to the edger.

7. As boards emerge from the edger, they drop on a deck chain which carries them to the trimmer.

8. Additional equipment includes a sawdust conveyer for carrying off the dust, as it falls beneath the saw, through a flue provided for that purpose. We also have a small pumping system for circulation of water past the sash guide slides.

9. Filing equipment is, of course, a very important item, as proper filing is especially important in the use of this mill. Our equipment includes a small torch used for brazing, welding and tensioning saws. Also included is an automatic saw sharpener and a hammering anvil.

Capacity

The largest factor that effects the capacity of the saw mill is the size of logs. Although the rate of feed is considerably less on the larger logs, the lumber output always exceeds that from the smaller size. I believe 12 inches or 14 inches is the ideal size for the mill we have. The speed of the cut varies from 10 feet per minute in an 18-inch log to 25 feet per minute in a 6-inch log. We find that, including delay time, our cut averages about 14 feet per minute. Our logs average 9 inches plus in diameter and our average cut over the past two and one-half years, has been 3,150 feet per hour. Knotty or crooked logs also are a large factor in determining the amount of cut. However, I believe that the gangsaw, in spite of reduced speed, will give a higher output than any other type of mill from these less desirable logs for they usually reduce the cut of any type mill. In fact I am positive that the small hardsided pine, so difficult to saw due to the fact that it "springs", will yield accurate lumber only by use of a gangsaw.

Generally I would say that in the same type logs, the gang mill will about double the cut of the average size circular mill when the same number of men are used. I believe it will about equal the cut of the 4-foot band and run about two-thirds of the cut of the 6-inch band, based on the same average size of log.

Utilization

Mr. Milton Applefield, post-graduate student at the Duke University School of Forestry, made quite an extended study of our operation in connection with his thesis and all the figures as to utilization and yield are furnished by him.

The study was based on 2,086 logs cut over a period of 11 days, broken down into one-half day units. The log sizes ranged from 6 inches to 17 inches in diameter and from 10 feet to 16 feet in length.

The following log sizes were observed and tallied:

Length in feet	No. of logs	Percent of Total of 2,086 logs
10	40	1.92
12	437	20.95
14	487	23.34
16	1,122	53.79

The breakdown of log size by diameter follows:

Dia. Class Inches	No. of logs	Percent of total
6	65	3.12
7	186	8.92
8	489	23.44
9	401	19.22
10	337	16.15
11	254	12.18
12	159	7.62
13	123	5.89
14	53	2.54
15	16	.77
16	2	.10
17	1	.05

The average log was 9.55 inches in diameter. The gross time for the sawing of these logs was 49 hours 35 minutes. The operating time was 47 hours 11 minutes while delay time was 2 hours 24 minutes for the entire study period.

These 2,086 logs produced 119,722 F.B.M. mill tally. By the Scribner log rule these logs scaled 96,720 feet b.m., showing a total overrun of 23.78 percent. By the International One-Quarter Inch log rule these logs scaled 117,035 feet b.m. showing a total overrun of 2.30 percent. By assuming each log to be a true cylinder; the size being that of the top diameter inside the bark, and the length of each log, the cubic foot volume of logs was determined to be 15,983.97 cu. ft. The sawn cu. ft. vol. was found to be 9,976.83 cu. ft. The balance, then, between the cu. ft. of lumber and the cu. ft. of logs is 6,007.14 cu. ft., which represents the waste, due to conversion from logs to lumber, of 37.58 percent.

In the statistical analysis to which this mill was subjected, all the principal variable factors which influence the time element and the volume of production were considered and tested for significance. For the time element it was found that only the

number of logs and the cubic foot volume, represented by the diameter squared times the length, were significant. Through the statistical method known as regression, a mathematical formula was computed to ascertain the operating time required to cut any log of any given dimension. The formula for operating time for this mill is as follows:

$$\text{Operating time} = .1036N + .000894 \times D^2L.$$

In this formula, N represents one log, D^2 represents the average diameter squared in inches and the L represents the length in feet. Thus, by substituting the diameter and length for any one log, the operating time can be ascertained.

In the determination of a formula for volume of any one log, it was found that only the cubic foot content of logs was significant and likewise through regression, the formula for volume follows:

$$\text{Vol.} = .040820 \times D^2L$$

In this case, also, the D^2 represents the average diameter in inches squared and L represents the length in feet. Thus, by substituting for any log, the diameter and length and following through the mathematics indicated, the volume for any size log can be obtained and this can be converted to a per feet b.m. basis.

Costs

Using an average hourly labor rate of ninety cents, labor cost per M will run from $4.00 to $6.00. By use of a "rule of thumb", this figure can be doubled to give total sawing cost. Any attempt to give more exact sawing cost may be confusing because of the great number of variables, such as size and texture of logs, thickness of boards, edging method, etc. One advantage of the gangsaw is that there are fewer highly skilled men required and less is left to the discretion of the workers, which in our case is usually very questionable. The filer, of course, is the most highly paid and most skilled man. We use one filer and helper for filing the gang, a band rip saw, a band resaw and about thirty circular trim saws. We consider that about one-half of the filers' time is devoted to the upkeep of the gangsaws. As to the cost of saws, these have risen more in proportion than other type saws and now sell for around $18.00 each.

As prime power we use a 150 h.p. electric motor.One hund ed h.p. is recommended by the manufacturer, but as is usually the case, we did not find this sufficient and have replaced our original motor. Other power required is for the smaller motors on the log deck, carriage chain, hydraulic pump, water pump, roll case, edger and filing room equipment.

Cost of supplies and repairs averages about $1.00 per M. Included in this item are replacement of saws, miscellaneous parts, repairs and replacements, hydraulic oil and any other item directly chargeable to the machine. Operating overhead averages about $3.00 per M. Included in th's item are one-half of the filer's salary, insurance, power, depreciation, shop expense and all other expenses not directly chargeable to any single department. Administrative overhead is not included in the above.

Quality of Lumber

One of the most serious objections of most people to round gangsaws, is that lumber grade recovery is sacrificed. Of course this is true provided the grade is not recovered by edging or trimming. In the case of low-grade logs, this is not necessary and, therefore, there is not much doubt that gangsawing has an advantage in this type of operation. Where flooring or other narrow stock is desired, the output of gangsaws is not objectionable either and the flooring strips contain much edge grain stock.

Conclusions

It would be impossible to reach any general conclusion as to which type of mill is to be preferred. The most important factor would be the type of business in which the owners are engaged. For instance, the mill supplying railroad car material would have very little use for a gang unless the output was sufficiently large that only the logs intended for boards would be sawn by the gang. On the other hand, a mill supplying shed stock and mixed cars or finished flooring and molding probably would find that a gangsaw fits nicely into its operation. Logs, of course, are the largest determining factor. It would be my opinion that either extremely low-grade or extremely high-grade logs are best suited to a gangsaw.

Discussion

Fred E. Dickinson (Yale University): Do you cant for the gangsaw and, if so what is your policy with reference to cant thickness?

Mr. Dargan: We do some canting for the gangsaw although we believe that the gang is most effective on round logs. The thickness of our cants is in even inches from 4 to 12. Of course, in making the cant, we pull down to the knots as nearly as possible.

Robert C. Fraunberger (Philco Corporation): What has been your experience on average Doyle Log Scale runs?

Mr. Dargan: Our experience on Doyle over-run has been from 40 to 80 percent. I realize this is a very broad figure but over-run can depend upon method of scaling logs, size of logs, edging and trimming of boards, etc.

Mr. Chapman (Bethel, Maine): Does the gangsaw cut down on cost of operation?

Mr. Dargan: Yes, the gangsaw will cut down on the cost of operation because there are fewer men in the crew; except for the filer, no highly skilled workmen are needed; and the high rate of utilization of a log will increase the volume coming from the saw and thus reduce the cost.

Richard A. Hale (R. A. Hale Logging & Lumber): Can the gangsaw be used on extremely crooked logs, such as New England pine for box boards?

Mr. Dargan: I think it could. While a crooked log is hard to saw efficiently in any operation, a gangsaw will yield more from it, although much time is generally consumed.

J. H. Kraemer (Lumber & Wood Products Division, National Production Authority): Have you made any studies regarding the smoothness of boards from the gangsaw as compared to those from the typical small sawmill? I have seen large permanent mills in Norway, Sweden and Finland operating gangsaws, and have been impressed with the accuracy of the thicknesses as well as the smoothness of the surfaces.

Mr. Dargan: Generally the surfaces are smoother with the gangsaw. The fact that the European gangs have a better surface can be accounted for, in my opinion, by the fact that this sawing is done at about one-half the speed we use.

Roy B. Peterson (U. S. National Production Authority): Gangsawn lumber when processed on a mill in good mechanical condition and fitted with properly conditioned saw blades is definitely smoother than lumber produced by the circular sawmill method. A talk was given on this subject at the Saw Mill Breakfast of the Southern Pine Association meeting in New Orleans last April and reprinted by the Southern Lumberman May 15, 1951, pages 28 and 84.

Frank B. Palmer (Palmer Machinery Company): Compare sash gang efficiency with circular gangs or bull edgers.

Mr. Dargan: For permanent installation the sash gang is better. The bull edger is not as bad as painted. Due to their extreme accuracy and high capacity, much of the kerf loss can be tolerated.

Mr. Dickinson: What is your policy with reference to the use of the gangsaw—to first slab the logs on two sides with a band or circular saw and perhaps remove material of B and better quality from those two faces before gangsawing, or to gangsaw the log without preliminary slabbing? Which method do you think is preferable?

Mr. Dargan: Most of our sawing is done on round logs.

I. V. Anderson (U. S. Forest Service): Was the overrun figure of 23.78 percent based on green tally or shipping tally.

Mr. Dargan: Green tally.

The Possibilities of Tropical Hardwood Production

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The successful development of tropical hardwood production demands an understanding of and action on diverse problems of weather, transportation, logging methods and equipment, timber purchase, health, financing, and public relations at both community and national levels.

AFTER more than a century of trial and forty years of intermittent preachment we can look upon relatively little in the way of large scale accomplishment in the production and utilization of tropical hardwoods. Since the turn of the century the timber industry of the Philippines has been built up and more recently considerable activity has developed in West Africa. In general, however, the vast tropical hardwood forests show little of the often promised extensive developments. With the exception of some half dozen woods, we do not import appreciable quantities of any timber species we did not handle forty years ago. Hundreds of thousands of square miles of hardwood forests, untouched or cleared periodically for agriculture, attest to the general lack of forest products industries in these regions. The continued existence of large accessible reservoirs of timber in the face of ever-increasing demands is an anomaly worthy of examination.

The present status was not attained by simple neglect. Indeed the entire history of the problem is fraught with political and commercial intrigue, fortunes made and lost and, on occasion, wholesale bloodshed. The traffic in rare timbers from the headwaters of the Nile and that associated with the earliest trade with India take us back into antiquity. Piracy was stimulated by the enormously valuable cargoes of logwood from the West Indies and Central America when Spain was the power of the region. Sandalwood exploitations swept Hawaii into a prominence from which it never receded although little remains of the timber that started it all. The mahogany business, with supplies from the West Indies and Central America was flourishing in the 1700's.

More recently scattered successful ventures have been started; some are thriving today. All too often, however, the culmination has been in dismal failure. Occasionally a well financed and apparently well organized attempt is made to harvest tropical timbers on a grand scale. I am told that a small portable mill now operates in a big four-head-saw plant built to cut Nicaraguan pine. Little remains of the modern mill and dry-kiln operation that attempted to harvest a large variety of Amazonian timbers a comparatively few years ago. A few rotted timbers and scattered fragments of rusted machinery mark the sites of numerous similar attempts to wrest a profit from the ubiquitous jungle. Hundreds of other similar projects died at or before birth.

What then is the verdict? Shall we continue to search in the farthest reaches of the Earth for a few proven valuable woods and discount all others as "valueless"? Or shall we ignore the haphazard experiences of the past, set up "modern" production plants and start clear-cutting operations in all the tropical regions of the world? Obviously we should do neither, but if we carefully analyze all of the problems that confront such an enterprise and if we balance these against significant economic changes, together with the great technological advances of recent years, it is not difficult to point out existing locations and conditions that are most promising for immediate development. We are reaching the stage where new machinery, processes, and "know-how" make it more profitable to mine the low-grade ore in large volume than it is to search for veins and nuggets. Axiomatic is the need for careful preliminary assay, survey, and process planning that precedes such operations. Careful examination of past causes of failure reveals nothing that should prevent great expansion of tropical hardwood facilities at the present time.

There are many reasons for the failure of specific endeavors and their recounting reveals an amazing array of causes including revolutions, political intrigue, tropical storms, change of demand, etc. All too often, however, the major basic reasons for failure have been (1) lack of detailed technical information and experience, (2) insufficient planning and business sagacity, or (3) inadequate marketing.

Production Problems

Weather is easily the greatest single problem of tropical hardwood production. Serious as it is, however, its effects have been exaggerated in many regions. Often there are great differences between the climates of regions less than a hundred miles apart or having one to three thousand feet difference in elevation. Some of these tropical locations favorably combine position with elevation so as to pro-

Fig. 1.—Hauling Possumwood logs in Surinam.

duce what many claim are the most salubrious climatic conditions to be found in the world.

Strangely enough *temperature* is not the most serious problem in tropical countries. Certain precautions are necessary, particularly with regard to salt and water consumption and head covering through the middle of the day. It is probably true that men cannot accomplish as much in a day's work under tropical conditions as is expected in temperate regions but much of this difference cannot be attributed to heat. Certainly the temperatures are often much higher for short periods in our middle-western corn belt than they are in the tropical rain forests. The slow-down of the northerner is, in large part, the result of unconsciously gearing himself to the pace of the community and the psychologically depressing effect of weather monotony. As far as labor in the tropics is concerned the great depressants are (1) poor general health from lack of medical and dental service, (2) serious dietary deficiencies, and (3) absence of stimulus induced by opportunity for income and desirable goods to purchase. All three of these can be remedied for a small community by a timber enterprise, with amazingly rapid results. The thought, effort, and comparatively small extra expenditure required would be amply repaid in increased productivity, not to mention community strength and political stability.

The problem of *health* in tropical countries has largely been answered by advances in medical knowledge, new drugs, and air transportation. With reasonable precautions the physical well-being of individuals in tropical countries can be equal to that of most of the United States and may be better than that of some smog-afflicted cities. Excessive alcohol consumption has probably broken the health of far more northerners in the tropics than has disease. Mental "health" of imported supervision and labor, particularly through the rainy season, can be maintained by providing facilities for both physical and mental recreation.

Rain, in torrential downpours day after day all through the long "rainy season," is the weather factor that stands squarely in the path of efficient operations over vast areas of tropical forests.[1] In most regions there is a "dry season" of about three months during which precipitation is scattered and comparatively small in amount, roads become hard and dusty, great areas of soggy river flats become dry enough to support trucks and tractors, and rivers

[1] Semi-desert regions, although supplying a few valuable woods, are not considered in this discussion.

diminish in size so that temporary bridges can be thrown across. The month preceding and following the dry season usually has reduced rainfall and dry-season operations are carried on to a varying extent during these periods. Some regions have a short, often only two or four weeks, semi-dry period at some time during the rainy period. A few regions have only one distinct season with only minor periodic variations in the distribution of rainfall which may total 250 inches or more per year.

High among the critical items of the tropical operation is *transportation*. It begins with the log in the woods, leads to the river, railroad or road; thence to the mill or dock, then to the country of sale. From many ports shipping is intermittent or infrequent, necessitating expensive chartering or inadequate service. If the volume of production is large and the bulk of the cargo of a single ship can be consigned to one destination then this item can be controlled through arrangement with existing shipping concerns, charter, or ownership. If the production is comparatively small or is to be delivered at widely scattered ports partial dependence upon tramp freighters or trans-shipment on small coastwise ships may be involved. Such conditions might necessitate special storage facilities, extra handling with attendant loss and costs, and questionable cargo shipment conditions (e.g. humid holds, bad loading). The problem of shipping facilities is primarily one that should be carefully analyzed for availability, cost, regularity, and type prior to the establishment of the enterprise.

In most tropical forest areas there are no *roads* in the vicinity or even approaching that part of the country. The northern logger generally expects to make his woods roads but hopes to use public thoroughfares for long hauls. Even should these exist in tropical countries, it is improbable that they will stand up under logging trucks during the rainy season without considerable maintenance work—usually by the logger. Very recently in several parts of the world logging and hauling has been continued through part, or even all of the wet season. Better equipment is partly responsible but improved techniques are aiding the work. Roadways are cleared to greater width to permit more rapid drying of the surface. Roads are crowned, ditched and occasionally surfaced, when typically scarce rock can be found. Particular attention is given to soft flats where the heavy rains saturate the earth, removing all support for the roadway. Deep ditches can be used for drainage if sufficient slope exists but at best it is a continual struggle in some areas. Corduroy can be built cheaply but in addition to the usual problem of continual repair must be added the amazing rate at which decay and termites work under these stimulating (to them) conditions. There are reports of the use of surplus iron landing field mats for bad parts of tropical woods roads during the wet season—a most satisfactory answer if the cost is low enough. Sometimes a pair of adzed

Fig. 2.—Hand windlass sometimes used for skidding heavy logs. Photo by Whitford.

three-log rails, or heavy planks, floating on numerous log crossties will carry trucks over a particularly spongy stretch. When it is available on a short haul, sand can be worked into clay to improve the quality of the road surface.

There are many variants, of course, but the great bulk of all tropical *road materials* comprise only two types. The soil of low flats in swales and adjacent to rivers is usually black silt with a high percentage of organic matter, capable of absorbing large quantities of water. Most of the land in tropical countries, however, is a clay which commonly becomes reddish on exposure to the sun. This clay differs materially from the slick but tenacious material usually found in this country. When dry it is hard and firm, its exposed surface broken into numerous small squares. During a heavy rain it absorbs an amazing amount of the downfall, the surface becomes slippery but the base remains firm. If exposed to the tropical sun it soon hardens on the surface and a half-hour later it is possible to walk across it without muddying more than the soles of one's shoes. Obviously in sheltered places, depressions, and where an organic overlay reduces evaporation the water content builds up so that the soft "surface" becomes increasingly thick. It is the belief of many that a sound knowledge of these soil characteristics, good road engineering, improved equipment, and ingenuity will make possible the trucking of logs out of tropical forests throughout most of the rainy season.

Public *railroads* do not exist or run only through the more heavily populated areas. Logging railroads are used in some regions, notably the Philippines. Improvised log cars running on metal or wood rails and moved by various power sources are of limited occurrence. Cars with large double-flanged wheels running on round-pole rails have been used to a very limited extent. Presumably, rapid deterioration of rails and crossties would be a factor for the main portions of such a line but this could be greatly reduced through the use of durable woods or simple

"on the job" preservative treatments. There are doubtless areas where light rail equipment of some kind can be made to serve better than trucks through the wet season. As with extensive road systems, however, no large railroad expenditures should be made without first having a detailed timber cruise and operations analysis.

With both truck and rail transportation the matter of *bridges* is of paramount importance. Bridge timbers are usually abundant, very durable, and extremely strong. Unfortunately these same timbers are usually very hard and very heavy so that the foremen or workmen are inclined to use softer, lighter weight, non-durable woods—much to the benefit of the ever-present fungus and termites. The enormous increase in size of many rivers during the rainy season poses a problem, even for bridges to be used only during the dry season. Often the bridge is built as short as possible with the result that not only the bridge but the approaches as well are taken out by the high water of the following season.

Transport by water is still a cheap means of moving logs and lumber and the numerous large rivers that characterize many of the extensive undeveloped tropical rain forest areas often appear to be the answer to the main transportation problem. Unfortunately these are usually totally unimproved waterways and a discouraging number have huge sand bars at their mouths, rapids block some at varying distances from the coast, and some are clogged with huge trees and other debris that accompanies excessive floods off some watersheds. Fortunately the rapids on most rivers that traverse large areas of tropical rain forest are situated well back from the coast but the problem of by-passing them without excessive handling costs is still in need of ingenious solution. In all but a few rivers it is feasible to clean the debris from a channel but the cutting of a channel through a bar at the mouth is often a large and perennial task. Unless the timber operation is to be large and well financed, and the necessary heavy dredging equipment obtained under favorable loan or rental terms it probably will not prove feasible to open most rivers. Shallow draft, small ships (such as landing craft) have been tried on a number of occasions with generally poor success. When all conditions are favorable the mill or ocean ship loading point may be located at a developed harbor some distance away along the coast, an arrangement which sometimes can be made to solve economically the two-fold problem of a bar at the river mouth and lack of port-of-call facilities for shipping.

River driving is practiced extensively with varying results. It is a cheap way of moving large quantities of logs and water storage is a partial protection against insect damage, stain, and splitting. Logs are cut during the dry season and hauled to the river bank or to a basin in the river where they await the first high water of the wet season. Logs of dense-wooded species or others that are likely to become sinkers are lashed with vines to low density logs. With well behaved rivers the drive may have few untoward incidents but it is not unusual for torrential downpours to spill a tropical river over

Fig. 3.—Primitive rail-haul system. Photo by Whitford.

its banks to flood miles of adjacent land, leaving some logs stranded deep in the forest and carrying others uncontrollably out to sea. Concommitant with this risk is the deterioration of logs lying on the river bank awaiting the drive and of the exposed portions of floating logs. However, if logging is being done only during the dry season this deterioration need be no more than that attendant to other types of transport—provided proper control measures are taken.

Any discussion of transportation is incomplete without mention of *air travel,* particularly as it applies to personnel. Numerous feeder airlines to out-of-the-way communities and private airfields for small planes have opened the tropical frontier to movement undreamed of a few years ago. Unquestionably work in back-woods camps will be more appealing henceforth to skilled labor and technical personnel alike.

Logging methods vary appreciably in different forest types, terrain, and countries. Faced with many unusual problems one would expect to find in tropical forests many interesting developments in this important phase of the industry. Unfortunately such has not been the case. The unique forests of the Philippines permitted the use of the West Coast's high lead system and heavy tractors are now commonplace there and in the mahogany camps of Central America and Africa. Tractors and trucks are working in many localities but in a great many places logs are still rolled or dragged by man-power to the river. Versions of the old man-powered Spanish windlass are still used for extra heavy logs. Oxen and buffalo are used in comparatively few scattered areas. Crude or inadequate versions of high wheels are sometimes used to increase the capacity of typically under-powered tractors or trucks. Towing winches on tractors are used for bunching and skidding to a limited extent but are probably used more for rescuing tractors and trucks bogged down in mud. Extra wide treads are occasionally noted on crawler type tractors and a few concerns have superb trucks with powered tandem rear axles or front and rear wheel drives, but generally the mechanical equipment is not especially adapted to the conditions under which it will be used. Improved equipment and methods must be devised for the job at hand if logs are to be brought out of the tropical rain forests at a reasonable cost during the wet season.

Felling of trees and *bucking* of logs may present a considerable problem. Splits, broomed ends, and cross-breaks attest to the bad felling practices of many regions. The axmanship of native loggers may be excellent or very poor. Commonly the men are trained not only to cut the tree down but to chop it to length as well. Often it is then squared with an ax and, in some localities, is also given a boat-shaped nose and has a hole bored through for fastening the skidding chain! In many areas there is a complete lack of familiarity with the cross-cut saw. It is probable that it would be easier to teach good log bucking with a power chain-saw than with the two-man cross-cut saw.

The question of *machine and equipment size* has an important bearing upon the size and production rate of the operation, and the investment required. In tropical forests it is not always easy to arrive at a decision on this problem because of the variation found in many of the stands. Such woods as mahogany, cedro (Spanish cedar), sapele, guanacaste, mora, kpendei, and others frequently exceed six feet in diameter but it would not be unusual to find that the bulk of the logs being handled ranged from 20 to 48 inches in diameter. Large size tractors and trucks needed for the big logs can be made to pay their way with larger loads of smaller logs but the sawmill or veneer lathe must produce economically from the bulk of material handled regardless of the value of very large logs. Probably the best method of producing lumber from many tropical forests is through the use of a bandsaw large enough to handle the largest logs. A large circular mill with an overhead saw will handle large logs with fewer skilled workmen and a lower investment than the band sawmill and is generally preferred for most tropical operations. However, it will produce much less per day, has a lower recovery from the log, and generally produces less accurately sawn lumber than a bandsaw. The question of size of equipment applies to other mill items as well. For example, if the planer and a market are available it may well prove feasible to produce long boards up to 36 inches wide for counter tops, table tops, pattern stock, church seats, or other specialty items. A veneer lathe capable of handling logs six feet in diameter is an expensive piece of equipment for use where logs infrequently exceed 48 inches, but big logs contain large volumes of very high grade veneer. In general, the problem is one of ascertaining as accurately as possible the sizes and quantities of the available logs, and both the quantity and the relative value of large diameter logs. From these data the decisions as to equipment size can be made.

Deterioration of equipment is extremely rapid in tropical regions. Fortunately a great deal of information has been accumulated during the last 10 years so that machinery companies, oil companies and others can supply especially prepared products. Of particular importance are shafting, gears, cutting steels, and electrical equipment of all kinds. Where it is not feasible to provide corrosion resistant metals excellent oil-like rust preventives are available and satisfactory if applied to clean, dry surfaces at the end of each working day.

Building deterioration is of such importance that much of the construction in the tropics is either of concrete or mortar and tile, with most wood construction considered "temporary." Durable posts and timbers with the ever-present corrugated iron are used for many factory buildings. Treated lumber and timbers would be an excellent solution but these

Fig. 4.—Lauan forest, Philippines.

are seldom available. Concrete floors are considered necessary in most factories and concrete posts with steel cross-rails are the surest means of keeping avaricious tropical termites out of the air-seasoning piles.

Log and product deterioration is a very large item, and one which is not given proper attention even in this country. Logs of many species suffer severe insect damage after prolonged exposure with the bark on and most logs will end-split badly if unprotected for considerable periods. Light-colored woods such as limba, samba, aceituna, and cativo will stain severely and suffer insect attack after very short periods of exposure. Good chemical treatments and end coating should keep the logs insect free for six to twelve weeks and should greatly retard staining. Proper control measures, manufacturing and seasoning methods, and rapid handling will give a high yield of clear, stain-free stock. Obviously the more perishable light-colored woods must be logged during the wet season if a continuous supply of bright material is required.

During the dry period the *seasoning* and storage of lumber and veneer does not differ materially from similar operations in this country. During the rainy season high humidities and excessive rainfall impose limitations and special problems. Air-seasoning piles require large, tight roofs, considerable pitch and slope, good ventilation under and between piles, and thick stickers that are either stain resistant wood or have been chemically treated. Even with these precautions drying will be slow in some regions and require a dry season to bring the material to less than 25 percent moisture content. There are fewer difficulties in connection with kiln drying, regardless of outside humidity conditions. In periods of high humidity exposed veneers approach a stabilized condition near 20 percent in a few hours after leaving the drier; lumber regains moisture in a similar but much slower manner. These conditions may limit the lowest moisture content at which exported materials may be landed, depending upon frequency and conditions of shipment, but they need not interfere with a well-planned production.

Management Problems

The *locating* of a suitable tropical hardwood tract has more often been achieved through chance than by an organized search. Tropical countries abound with tales of vast areas in which all trees are giants and as close as pickets on a fence. If these stories are methodically sought out and one does not become discouraged by innumerable fruitless trips into the forests, an occasional valuable tract will be found. All too often, however, the story has been embellished with re-telling and frequently can be traced back to the grandfather of the present owner—neither of whom ever visited the interior of the property. Three general approaches may be used to find a favorable location for tropical operations. The first involves the selection of a particular species of wood and the search for profitable stands of this species within its range of distribution. Such is the means of establishing an operation in mahogany, cocobolo, rosewood, limba, ocote pine, or Philippine mahogany. The second method is to locate tracts of timber carrying large quantities of good-sized trees and then to determine its potentialities from the standpoint of its wood and business aspects. The third method is to locate a region, country, and finally a site which is in a suitable forested area and yet offers favorable advantages from the standpoint of shipping, local markets, labor, and political situation. There is no best method and the final analysis should weigh the desires and experience of the operating group. If they can produce timber cheaply under frontier conditions but do not have an excellent selling arrangement then they should follow the first approach, producing a wood which has an established market. If their primary interest is to obtain several good woods in volume at low cost and marketing is not a major problem, the second suggestion can be used. Finally, if the plan is to set up a permanent industry that will utilize a considerable number of woods and expand to produce a variety of products for local use as well as export, the third approach will usually prove most feasible.

Although most tropical forests are *mixtures of species,* there are certain areas in which 50 to 90 percent of the volume is of one species or is composed of closely related species. Among these are the San Juan, cedro macho, roble, cativo, orey, mora, greenheart, mangrove, "supucaias" and wallaba of

the Americas; otabo, ekki, okoume, corkwood, limba, and others of West Africa; and the omnipresent dipterocarps of Malaya, the Philippines, and the southwest Pacific islands. In most regions large areas can be found in which a single group of species predominates. The major consideration is the harvesting of as large a volume (number of species) as possible per acre so as to spread the fixed costs of logging. This general philosophy is disputed in practice in the case of certain high value timbers logged during a very short period of time each year, in which the comparatively large profit per tree is expected to cover the rapidly depreciated investment, and where the taking of lower value species would only reduce the volume of higher value trees extracted.

Timber supplies are generally available on three different bases in tropical countries. The first and best known is the concession obtained from the government. Briefly this amounts to a license to operate a certain area of government-owned timber land over a given period of time and usually involves an initial payment plus a fee per thousand board feet or per tree for the material removed. The second basis is the outright ownership of a tract of timberland. Large holdings are available in many countries for purchase or in exchange for company stock. A third method of supply has many ramifications but typically involves purchase from owners on a contract basis or purchase from people operating on government land which they have under concession. Of these three forms, the first two offer the greatest assurance of continued supply, the second is the safest from the standpoint of governmental interference, and the third may yield the cheapest logs.

In most countries there are a number of individuals who offer their services as *"contract loggers."* These men usually have a small amount of poor equipment and a number of men they can obtain on short notice to make up a woods crew. Usually they require an advance for supplies, repairs, and purchase of additional equipment. Heavy equipment that is needed will be purchased with the advance or by the buyer who will deduct a portion or all of the purchase price from the value of logs delivered. With a few exceptions these contract loggers work on too small a margin with poor equipment and often they are poor managers as well. Thus the usual procedure involves additional advances during the logging season and final upward adjustment of the scale of payment at the end of the season. The experienced buyer knows his logger and the timber to be logged and makes his own estimate of the final cost which may differ materially from that of the original agreed-upon price. The unsatisfactory results of this system have caused many concerns to do their own logging wholly or in part.

There is an anomalous individual in most tropical countries who might best be given the title of *"free lance log buyer."* In cities and in other countries his small advertisements and large letterheads imply that he is a bona fide timber producer. Armed with an order he will attempt to obtain the logs by purchase through small local sources, sub-contract to a logger, or pass the word out to a considerable number of individuals living in the hills and forests who will in turn bring in from one to several logs each. Such operators may do a service in accumulating supplies of widely scattered very rare woods but their record of past activities, studded with failures to deliver the correct timber in good condition, has been responsible for much of the discouraging history of tropical woods utilization.

The question of partial *manufacture* near the source of the timber as opposed to the importation of logs for manufacture in this country is worthy of very careful analysis. High U. S. labor costs, ever increasing freight rates, and the encouragement of governments makes foreign manufacturing a more promising enterprise now than it did a few years ago. Manufacture near the source permits utilization of lower quality logs and closer selection of high-quality product for export. Shipping costs of usable material are much less, as for example: A 30-inch by 16-foot log of wood having the density of yellow poplar will yield about 675 bd. ft. of air-dry lumber weighing approximately 1600 pounds. The green log at a moisture content of 90 percent would weigh a ton more than this. At a $16-freight rate it would be necessary to add $24 per M cost for "nothing." Further advantages would accrue from the dropping of trim ends, material degraded in seasoning, elimination of defects hidden in the log, and reduction of degrade in transit. More favorable treatment in matters of taxes and concessions is generally extended by foreign governments to established manufacturers in preference to log exporters. The working off of part of the manufacturing costs where labor and taxes are less is an important

Fig. 5.—Bucking a Lauan log.

method of overcoming the added freight and handling costs of tropical woods.

Size of operation is a critical factor that is difficult to analyze precisely. There are often many good reasons for starting small and expanding later, including a limited local supply of trained men, poorly developed transportation facilities, inadequate associated industries and businesses (food stuffs, machine shop, hardware, etc.), lack of water and sanitation facilities, and other deficiencies peculiar to the particular area. Often, however, the large sizes of the timber to be handled require heavy equipment which in turn must produce considerable volume to pay for itself, leading inevitably to a larger mill set-up. A working compromise can be achieved by planning a medium to rather large operation in detail and then eliminating all but the smallest possible number of most essential items. With some adjustments the resulting logging or milling set-up can be classed as a rather small operation with equipment capable of handling large logs and so constituted that expansion can be undertaken without costly changes. In this initial phase there should be no compromise with quality nor with the minimum size of equipment needed for efficient operation. In certain remote locations the productive capacity of the operations must be great enough to furnish regular shipments of sufficient volume to establish it as a port of call or to make up regular charter shipments.

In the final reckoning the quality of *supervision* will dictate the degree of success of the tropical timber enterprise. Excellent supervision during the formative period is essential to start the operation and to build a good working force. Skilled labor will be scarce and high priced and it requires patience and understanding as well as competence to train workmen. Insofar as is possible, all supervisory men on the operation should be gifted with the ability to do many different things in addition to their major task.

Technical information and control are a natural part of all modern business and nowhere in the wood industry is it more essential than among the multitudinous problems confronting a tropical operation. Three general types of technical "know-how" may be required to establish a new enterprise. To obtain information on the amount, kinds, and distribution of timber, and for the making of maps and laying out of roads a forester may be employed. Certain of this information is required before the selection or purchase of land or timber concession although it is an amazing truth that many otherwise sagacious businessmen have not only spent large sums of money on unexamined concessions but have also bought machinery and built expensive roads with which to bring out the non-existing timber. Such predicaments stem from unwillingness to make a proper examination or timber cruise, or from incompetence of employees. The second type of technical information is that related to logging and which permits taking full advantage of the many recently developed devices and methods of handling logs more efficiently. The third area of required technical information and control is in the manufacturing plant where special saws, deterioration control treatments, seasoning practices and moisture control, special handling methods, new products, etc. should be used to solve the many problems peculiar to tropical woods and to keep the operation abreast of modern practice. The personnel for these tasks may be especially hired for each phase, may be a single man, or may be part of the regular production-supervisory staff. It is essential, however, to realize that the technical aspects of operations under tropical conditions can easily mean the difference between failure and highly profitable operation.

An unusually large amount of careful *planning* is necessary in an operation of such complexity. Part of this is done in connection with the preliminary survey and business decisions but analysis of details should follow the initial phase. The laying out of cutting areas to fit the seasonal logging conditions as well as the production schedule of volumes for each kind of timber, quantity and kinds of saw teeth required, provisions for repairs, scheduling of production and shipping space, stain and insect control measures, anti-malarial pills for the workmen, the amount of moisture pick-up between drying and shipping in different seasons, the setting up of books and cost control records, shipment and installation of heavy machinery, and housing for supervisory personnel and skilled labor are but a random few of the items that must be represented in a well-ordered working plan. That such organization and planning is necessary may appear obvious but careful analysis of past abortive attempts to establish successful tropical timber operations will almost invariably show failure to consider all influencing items and the lack of a complete plan of action.

Local public relations have come to be of utmost importance to a successful business venture in tropical countries. No matter how much encouragement was given to the establishment of the venture initially the company and its owners remain "foreign" to the people. While this stigma and its associated handicaps can never be completely eliminated much can be done to remove its troublesome aspects. It first must be recognized that operations in tropical countries, regardless of location, have many or all of the problems of frontier conditions. For a successful, long-term operation, a portion of the amount from the lower wages must be re-invested in the development of better living conditions for labor and the community. The extent of such work that is undertaken will vary with the location, size, type, and permanence of the operation but even the smallest log contracting job in a remote jungle area should conduct certain phases, either directly or indirectly. The wage scale should be adjusted so that

a decent living is possible for the man and his family. This will probably be above that paid by local industry and may cause complications but the work return from the individual will become increasingly greater as his diet improves. A free or very low cost health service for the workman and his family will pay dividends in work output and good will. In some areas the company may have to improve the water and sanitary facilities of the community on its own initiative and at its own expense. Participation in school improvement programs will be greatly appreciated locally. Often it will be necessary to improve the local source of food, clothes, general merchandise (and eventually recreation) through a company store or, preferably, through the encouragement of locally owned stores. Similar assistance will quickly improve the quantity and quality of locally produced food stuffs of all kinds. An established mill should also help local trades and their shops, not only for community good will but also because such skilled labor need not be carried on the mill payroll. It is also a good plan to encourage small associated wood industries that can produce specialty items or completely manufactured goods for local consumption. The sponsorship or encouragement of needed industry other than wood-using is a long step but, like the preceding, will probably do more permanent good for the community and bring greater indirect returns to the parent company than will outright gifts. An industry that intends to go into the tropics on a long-time basis must rule out pure exploitation of resources and people; it must build its own strength, permanence, and security by welding a community of native people into its economic fabric. This requires planning and vision beyond that needed for a similar operation in the United States.

Local political relations, both real and imaginary, comprise one of the greatest deterrents to investment in tropical timber enterprises. The specter of revolution, expropriation, special taxes, and other politically sponsored machination is ever present. However, with a few notable exceptions the resentment against foreign business has in most countries been replaced by a respect for the benefits derived from the established industries. If the management has scrupulously avoided political entanglement the business can continue without interruption after, and usually during, the political "revolution."[2] The various elements of the public relations program outlined in the preceding paragraph offer the soundest means of securing public support and thus, freedom from political interference. In all countries there are educated, honest, and competent men who can be hired for various positions of responsibility and who, along with a benefited labor group, can do much to counteract any political opposition. Men of influence who are not involved in politics can be found in every country and if taken in as stockholders, directors, or as suppliers of timber under contract, can help bring immunity to political intrigue. In most countries today, it is not necessary to go to great lengths to protect a well managed progressive industry from governmental influence.

Taxes are low in most tropical countries and even these may be reduced considerably by agreement prior to the initiation of a new enterprise. It is wrong both socially and for the future security of the operation to take advantage of this situation. A successful business should pay its full share of the taxes in the country in which it is located and evasion, even through well meant earlier agreements, leaves the concern vulnerable to political condemnation or pressure. Perhaps the best basis for tax relief during the formative period is one that is scaled from zero to one hundred percent over a period of years. Where the tax is ridiculously low, a profitable operation would do well to strengthen its position in the community through voluntary support of schools, road building, public health programs, or libraries. One firm in Costa Rica claims to spend $1.00 per M. bd. ft. for such work. The purchase of local good will and the attendant protection from political and political-economic pressure is well worth such expenditures, made in lieu of higher taxes. The low *income taxes* of these countries offer one of the strongest attrac-

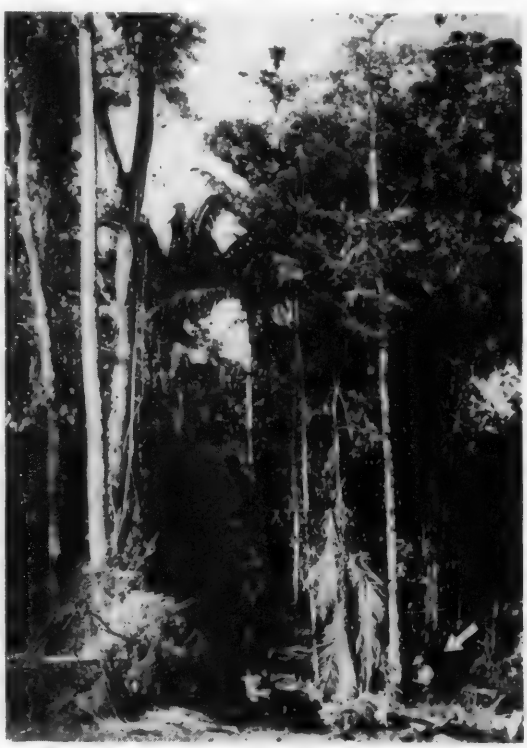

Fig. 6.—Forest in Eastern Nicaragua containing high percentages of Maria and Comé Negro trees.

[2] It should be recognized that most Central and South American revolutions are enormously exaggerated in our newspapers.

tions to the investment in and establishment of such enterprises. They offer a strong inducement to technical and production personnel, also.

The *financing* of an enterprise is a business problem and there is no substitute for business sagacity in an operation with as many complicating features as the one we have under consideration. Strangely enough there appears to be an exotic appeal to tropical investments, or perhaps it is the overpowering lure of three billion acres of timber awaiting the ax, which causes otherwise cautious businessmen to lay aside their hard-earned acumen and to assume that degrees of latitude bring about changes in economic principles. Regardless of cause, the disproportionately large number of losses engendered by poorly planned and conducted operations has caused many investors to be wary. Experienced wood-industrialists who have sales or wood-use connections, and who have carefully gathered all of the necessary facts, examined the proposed set-up, convinced themselves of its soundness, can make a success of tropical timber production today. The advantages of including individuals of the country of operation among the major investors should not be minimized, for while they often contribute little to the conduct of the business they can supply much local information and stability. Perhaps the U. S. government will interest itself in a practical approach to the industrial development of one of Latin America's few great resources. A philanthropic group could make no more effective demonstration of the establishment of economic prosperity than by simultaneously developing integrated tropical wood utilization units and agriculture in the same general area.

Marketing Problems

Nothing among the many points discussed is more essential to the success of an operation than good *marketing*. The obstacles to the introduction and establishment of a tropical wood on the U. S. market are largely a product of bad practices and unfortunate experience in the past. The first step is to establish a consistent supply of wood, true to name, of the quality stated, in good condition, and at a competitive price. While ability to "deliver on order" and "guarantee of product" are taken for granted in most of our merchandising, there are a great many individuals and companies anxious to produce and sell tropical timbers who are not in a position to meet the requirements. Obviously a producer must have an organization that can advertise and sell its product on a sound basis which will encourage re-order and expansion of markets. An attempt should be made to restrict the early use of a new wood to markets for which it is adapted so that blanket condemnation does not result from unwise application. Promotion that is directed toward specific applications and gives detailed methods of handling will avoid many difficulties inherent in attempts to sell a new wood as a substitute for a superficially similar well-known species. While it is true that several different woods can be used for most applications it is equally true that no two unrelated species are alike in all properties.

Local markets for wood products should have an important place in the production plan. In most tropical countries there is a strong demand for well-manufactured and well-seasoned material. Often durable woods are desired and frequently mill work is requested as well. Obviously this is a market that should be built up to absorb as much non-exportable wood as possible and it should be possible to introduce new woods to this market completely apart from the U. S. market.

The *marketing advantages* enjoyed by tropical hardwoods, when they are properly selected and produced, should include some of the following:

1. Large dimensions and high average quality.
2. Large available quantities.
3. Great variety of colors, grain patterns, and textures.
4. Exceptional properties for certain exacting uses.
5. Competitive prices.

The rewards can be rich for those with the ingenuity and skill to satisfy the architect's, designer's, and decorator's demands for new materials with unusual woods suitable for the purposes. As a single example, it has not occurred to many that the plastics designers have not only done the engineering but have also built up a market (for the asking) for decorative, dense tropical hardwoods.

Future Prospects

The demand for tropical hardwoods will unquestionably increase steadily in this country, in Europe, and especially in tropical countries. In the United States the requirements will be preponderantly for decorative and special purpose woods, large dimension and high-quality material, and high-grade veneer woods but an ever increasing quantity of general purpose hardwoods will be utilized as highest quality native material becomes scarcer. Tropical hardwoods will offer virtually no competition to native softwoods and while they should eventually supply an appreciable amount of the higher quality hardwood stock they will only supplement the native material and make up but a comparatively small percentage of the seven billion board feet of hardwood used annually. As best quality temperate zone woods become scarcer the outlook for the established tropical enterprises becomes increasingly brighter. When presently unknown woods are finally accepted on northern markets the tropical operator will be able to go back through his lightly cut-over forests on his old roads and twenty to thirty years hence he will find that the luxuriant growth of the tropical rain forest has built up another cut of sawlogs on the area.

Discussion

Mr. X: Is there any good white oak in Mexico or Central America?

Mr. Hess (The Mengel Company): Yes, undoubtedly there is some "white" oak of good quality, density, and texture in Mexico and Central America. Unfortunately, there are also a great many species which have dense wood, often coarse-textured, growing in mixture. The preponderance of the dense-wooded species together with the difficulties of identification makes sorting virtually impossible with our very limited information.

Mr. X: Would you recommend putting in a timber operation on the Amazon and why?

Mr. Hess: Various sites in the Amazon valley offer exceptionally promising opportunities for a successful timber operation. This same region, however, has an exceptionally high percentage of all the obstacles found in tropical forest exploitation enterprises. To be completely successful, a large operation would need to be prepared to take on and efficiently administer a great variety of activities, all the way from sanitation and recreation, through unusual technical control and novel logging methods, to the development of markets for unknown woods. Most companies in the wood industry are not yet ready to take on such an elaborate enterprise.

Mr. X: Can logging be carried out in the tropics during the rainy season?

Mr. Hess: Logging is being done during the tropical rainy season in several parts of the world. More of it will be done in the future.

Mr. X: Aren't most of the tropical hardwoods extremely hard and heavy?

Mr. Hess: Many tropical hardwoods are very dense; in some regions they make up the majority of the trees. There are, however, large volumes of medium to low density woods in the tropics, in some cases constituting the bulk of the stand over large areas. Low density woods are often perishable and frequently cannot be brought in log form to this country by the methods commonly used.

In most species of timber in which so-called ambrosia beetles attack the log after felling, the damage can be minimized or eliminated by proper application of suitable chemicals. When the value of the undamaged log is compared with the "wormy" log, the cost of chemical treatment usually can be justified if the original operation is economical. It is no more difficult to train a native to handle the chemicals and spray equipment than it is to produce skilled loggers or equipment operators from the same men.

S. Greenhouse (International Balsa Corporation): I agree wholeheartedly with the remarks of Professor Hess, if anything, he has minimized the difficulties encountered in importing new woods from the Tropics. One point in particular he passed over rather lightly, I think, and that is the effect of ambrosia beetle on such an undertaking. In my opinion the ambrosia beetle is one of the greatest causes of failure in a wood business undertaking in the tropics. Even after all the various difficulties as described by Professor Hess are overcome there is always the ambrosia beetle which riddles the finest woods and turns apparent success into failure. While there are several chemicals recommended for the control of this insect, their use is not always practicable since first, by the time they are delivered the cost is quite high, when freight and handling costs into the jungle are added to the original cost. The second reason is that it is exceedingly difficult to get native loggers to use the chemicals.

A. J. Panshin (Michigan State College): What could importers do to stimulate general acceptance of many tropical hardwoods?

Mr. Hess: Importers should accumulate all possible technical and use information concerning each particular wood and disseminate it as widely as possible. They should work with manufacturers until the eccentricities of the wood are learned and production problems solved. If the wood importers had one-tenth the number of "technical salesmen" that the glue industry uses, such woods as Idigbo, Bossi, and Obeche would be in common use in this country.

George N. Lamb (Mahogany Association, Inc.): In regard to Mr. Panshin's question—"What could importers do to stimulate general acceptance of many tropical hardwoods?"—this really was a $64 question.

Importers have been trying to find a market for the so-called secondary tropical woods for generations. At one time or another an effort has been made to find a market for practically every tropical wood that seems to have any possibility of acceptance by the woodworking trade in this country. When it comes to face veneers, almost any tropical wood will be given a trial by the veneer manufacturers, if it has a pleasing grain or figure.

The greatest difficulty in the past has been that a manufacturer may cut a few thousand feet of such veneer, show it to his customers, and perhaps find that someone is interested. The furniture manufacturer then wants to use 250,000 feet a month for a particular purpose. The veneer manufacturer cannot deliver at all, or only of a quality that is inferior to the original sample. He gives up in disgust and tells everybody else that the supply is not dependable. From a practical standpoint, it does not pay to do a promotion job on tropical woods for veneer purposes. A firm is much better off to stick to woods that have a proven market.

In the lumber end of the business, secondary tropical woods find a ready market when American hardwoods are scarce and expensive. A typical example was the case of cedro macho (Carapa guianensis). Right after the war, this wood was imported in very substantial quantities and found a rather

ready market in spite of the fact that there were difficulties involved in kiln drying and machining it. However, as soon as the good native hardwoods became more available, the demand for it dropped to almost nothing.

Another difficulty is that selective logging of a very few species or only single secondary species, makes the cost approach that of mahogany and in competition with mahogany, this secondary wood loses out. If the importer decides to cut all merchantable trees, regardless of species on a given tract, he finds himself with such a miscellaneous inventory of lumber that he cannot ship any one species without having it mixed with other things that may act very differently as it is manufactured into finished products.

I think that many of these secondary woods will gradually find a limited market and then a better one as time goes on, but from a practical standpoint there isn't much that the importers can do about it.

"How would you get a group together which would be interested in promoting foreign woods?" I asked this question of Professor Hess and frankly, I do not know the answer. I think it would be difficult to get a group together to promote any one of the secondary woods. The best example of a new tropical wood coming on the market in substantial quantities has been the importation of limba, which is being sold in this country as Korina. This wood was brought into considerable prominence by aggressive advertising by the United States Plywood Company. I think it will always be difficult for a tropical wood to compete with native hardwoods until the demand for tropical woods is such that the high cost of ocean transportation can be met and still show a profit.

Mr. Hess: There are several different approaches to this problem. Perhaps the most practicable would be to work with established manufacturers who are willing to make a real effort to use several tropical species in products they are now producing.

Robert C. Fraunberger (Philco Corporation): Do you think enough new plants will come into production to drive prices down to compete with local species?

Mr. Hess: No. As stated in the paper, the total volume of entering wood probably will represent but a small percentage of the annual consumption.

Mr. Fraunberger: Did your study include the new plants being established in West Africa?

Mr. Hess: Yes.

I. V. Anderson (U. S. Forest Service): What are the production problems in getting out Parana pine?

Max Pillow (U. S. Forest Products Laboratory): We have no information on production problems except that Parana pine is concentrated at or near ports from numerous mills. Lumber shipped to the United States is mostly select grades with common and shop grades used domestically in Brazil and Argentina. Our information indicates that importation is at a level of 50 to 60 million board feet annually.

Potter C. Palmer (Palmer Machining Company): Are there 37 species of tropical hardwoods available in commercial quantities?

Mr. Hess: Yes, I believe so.

Dr. Pillow: I also suggest the following reference: David A. Kribs, "Commercial Foreign Woods on the American Market," published by the author, Tropical Woods Laboratory, Dept. of Botany, Pennsylvania State College, State College, Pennsylvania. $6.50.

TECHNICAL SESSION II—Tuesday, May 8, 1951, 9:00 A. M.

General Subject: Mobilization of the Wood Industry

Chairman: J. Alfred Hall—**Recorder:** Wm. J. Delmhorst

The Current Situation Affecting Logging and Milling Equipment Availability

H. E. HOLMAN, *Lumber and Wood Products Division, National Production Authority*

The current high-production status of the forest products industries is pointed out and the trend to increasing production percentages from small mills is noted. Impending shortages of equipment and supplies are indicated and some measures of alleviation suggested.

Forest Products Industries at High Production Levels

THE equipment situation in the forest products industries was, on the whole, fairly satisfactory until the development of the Korean crisis. Since then, the defense agencies have become large claimants for materials and products, thus creating an abnormal demand for many items that formerly were in a rather closely balanced supply. During 1949 and 1950, some segments of the forest products industry produced at the highest level in history. To accomplish this, it was necessary to have an adequate supply of raw material, production equipment, manpower, and maintenance and operating supplies. There may have been a few isolated cases where the lack of certain types of equipment caused some difficulty during the latter part of 1950, but during the months of June through October of 1950 the lumber industry produced at the highest rate on record. Softwood plywood production also was at an all-time high. The hardwood plywood and veneer and the pulp, paper and board industries were able to increase their production substantially and to take care of all requirements on a fairly prompt basis. It is logical to assume that such generally unprecedented production was possible only because of an adequate supply of all the elements necessary for production.

Equipment Status of the Forest Products Industries

A picture could be presented that would indicate a generally satisfactory current supply of logging and milling equipment. The industry is taking care of the demand for the various forest products even though some operators are feeling the impact of equipment shortages. This provides no valid reason, however, for assuming that current conditions can be used as a measure of what lies ahead. At the present time we, unquestionably, are benefiting from the accumulation of equipment and supplies which took place during the years following the end of World War II. In late 1945 the producers of forest products found their facilities in a somewhat depleted condition insofar as adequate production equipment was concerned. The very intense shortages during the war period necessitated the application of all the ingenuity of the industry in order to maintain production. Immediately after the war, there was a rush to replace worn-out equipment and to purchase new types of equipment that had been developed. The machinery manufacturers found it necessary to go into high gear and to increase production substantially to take care of the accumulated deficit.

Even with this increased production capacity of the machinery manufacturers, it has not been possible for a buyer of equipment to place an order on what might be termed a cash-and-carry basis. There have been varying lags between order placement and delivery, depending on the type of equipment involved. The lag has not, however, been sufficiently serious to prevent accumulation by the forest products industries of some equipment capacity reserve.

Since the Korean incident, the industry has, in a sense, been living on its fat, equipment-wise, but the "fat" is rapidly being consumed and all indications forecast the development of an extremely serious situation because of the increasing lack of available capital equipment, and maintenance, repair, and operating supplies.

Make-up of the Industry

In order to get a more accurate estimate of what we may be facing in the months ahead, with respect to equipment and supplies, it is important that we know something of the make-up of the industry, particularly in the field of logging and sawmilling. Since 1942 there has been a rather interesting transition taking place in these two segments of the industry. Although actual figures are not available for logging operations, all evidence points to the fact that a very large portion of our log supply comes from the small operators, and the proportion increased remarkably during the last decade. In 1942 large mills of the South (which included mills cutting 5 million board feet or more) produced about 33 percent of the lumber. The smaller mills cutting

less than 5 million board feet produced 67 percent of the total cut of the Southern states. In 1946 the large mills produced only about 23 percent with the smaller mills accounting for 77 percent of the cut. During 1947 the larger mills increased their proportion of the total cut and accounted for 29 percent. So far as we are able to ascertain the number of large mills did not increase, but the production per mill was higher.

The large mills of the West, or those mills classified as cutting 50 million board feet or over, produced 43.7 percent of the Western lumber cut in 1942. Mills cutting between 25 million and 50 million feet produced 24.8 percent of the total, and the mills cutting less than 25 million board feet produced 31.5 percent. In 1947 the mills cutting 50 million feet or more produced only 23.9 percent of the Western lumber cut. The mills cutting 25 to 50 million feet about held their own, producing over 22.6 percent, and the smaller mills produced the balance, or 53.5 percent.

The significance of mill size becomes more astonishing when expressed in terms of number of mills and output per mill. In 1947, according to the Census of Manufactures, there were 53,109 sawmills in operation in the United States, of which 47,538 or 89.5 percent cut less than 1 million board feet per year with an average cut of only 191,000 board feet per mill. These small mills, however, accounted for 9,096 million board feet or 25.7 percent of the total production. There were only 4,467 mills in operation that cut between 1 million and 5 million board feet, or 8.4 percent of the total number of mills. These mills showed an average cut per mill of about 2 million feet, and accounted for 25.4 percent of the total cut. All the rest of the mills in the United States, or mills cutting 5 million feet or more per year numbered only 1,104, or 2.1 percent of the total mills in the country. Their average cut was 15,695,000 board feet and they made up 48.9 percent of the production in 1947. In other words, slightly over 51 percent of our total lumber production came from mills producing less than 5 million board feet per year. Table 1 shows the number of mills in the United States and production by regions and mill size classes, in 1947.

Equipment and Supplies Must Be Used With Maximum Efficiency

It is essential that we maintain maximum lumber production, and in order to achieve this objective it will be necessary to get the maximum efficiency of both production equipment and operation and maintenance supplies. The distribution of equipment and operation of maintenance supplies must, to a large degree, be governed by the use that will be made of these critical items and measured in terms of the amount and type of production that will result. This problem is complicated by the large number of small mills and logging operations that, in the aggregate,

TABLE 1.—LUMBER PRODUCTION AND NUMBER OF MILLS BY REGIONS AND MILL-SIZE CLASSES, 1947

Region and mill size class (board feet cut per year)	Aggregate production (million board feet)	No. of active sawmills	Average production per sawmill (million bd. ft.)	Percentages of U. S. totals: Production	Percentages of U. S. totals: No. of active mills	Percentages of region totals: Production	Percentages of region totals: No. of active mills	Idle sawmills in 1947: Number[1]	Idle sawmills in 1947: Percent to total mills[2] in region '47	New mills in 1948[3]	Indicated total number of sawmills 1948[4]
U. S. totals	35,404	53,109	.667	100.0	100.0	100.0	100.0	8,442	13.7	1,852	63,403
Mill size class:											
Under 1 million	9,096	47,538	.191	25.7	89.5	25.7	89.5				
1–4.9 million	8,981	4,467	2.011	25.4	8.4	25.4	8.4				
5 million and over	17,327	1,104	15.695	48.9	2.1	48.9	2.1				
Total West	16,336	4,961	3.293	46.1	9.3	100.0	100.0	439	8.1	126	5,526
Mill size class:											
Under 1 million	975	3,258	.299	2.7	6.1	6.0	65.7	Includes the North Pacific, South Pacific, North Rocky Mountain and South Rocky Mountain States			
1–4.9	2,501	1,050	2.382	7.1	2.0	15.3	21.2				
5–9.9	2,062	299	6.896	5.8	0.5	12.6	6.0				
10–24.9	6,894	{205	22.167	19.5	{0.4	42.2	{4.1				
25–49.9		{106			{0.2		{2.1				
50 million and over	3,904	41	90.790	11.0	0.1	23.9	0.9				
Total South	12,974	21,243	.611	36.6	40.0	100.0	100.0	2,663	11.1	867	24,773
Mill size class:											
Under 0.5 million	1,895	14,862	.128	5.4	28.0	14.6	69.9	Includes the Lower Mississippi, East Gulf and South Atlantic States			
0.5–0.9	2,586	3,569	.725	7.3	6.7	19.9	16.8				
1–2.9	3,382	2,080	1.626	9.5	3.9	26.1	9.8				
3–4.9	1,325	353	3.754	3.7	0.7	10.2	1.7				
5 million and over	3,786	379	9.989	10.7	0.7	29.2	1.8				
Total East (Excl. South)	6,094	26,905	.227	17.2	50.7	100.0	100.0	5,340	16.6	859	33,104
Mill size class:											
Under 0.5 million	2,192	23,775	.092	6.2	44.8	36.0	88.3	Includes the Central, Lake, Middle Atlantic, New England and Prairie States			
0.5–0.9	1,448	2,074	.698	4.1	3.9	23.8	7.7				
1–2.9	1,398	893	1.583	3.9	1.7	22.9	3.3				
3–4.9	375	101	3.713	1.1	0.2	6.1	0.4				
5 million and over	681	72	9.458	1.9	0.1	11.2	0.3				

[1]Sawmills that did not operate during any part of 1947.
[2]Sum of active mills (2nd. col.) and idle mills (8th col.).
[3]New sawmills found in the Census canvass during the first half of 1948 but which were not in existence in 1947.
[4]Sum of active and idle mills in 1947 (cols. 2 and 8) plus new mills in 1948 (col. 10).
Compiled by Forest Products Division, Office of Domestic Commerce, Department of Commerce from Census of Manufacturers, 1947, Bureau of the Census, Lumber and Timber Basic Products (MC24A).

produce a large proportion of our logs and lumber. Since many of these mills operate only a few months of the year, and since many of these operations are very inefficient insofar as the use value of equipment is concerned, it will be necessary to do a very careful screening job on equipment applications, if we are to get a volume and grade of material commensurate with its use value.

Materials Must Go Where Results Will Accrue

During the last war the Lumber and Lumber Products Division of WPB got what may be termed a direct allocation of equipment. The Division had to justify its requirements before the Requirements Committee and, upon receiving the allocation, it then became the Division's responsibility to distribute this equipment in a manner that would produce the best results. Under the Controlled Materials Plan, which will go into effect under the National Production Authority, we are in a similar situation and we find ourselves in the position where it will be necessary to distribute the allocations on a basis that will produce the best results. Obviously it is going to be necessary to evaluate each application for equipment on the basis of the ability of the applicant to perform in terms of defense requirements.

Shortages Being Felt

Unquestionably, it is going to be difficult to take care of all the requirements of the various segments of the lumber and wood products industries. Already the industry is beginning to feel the shortage of steel, aluminum, copper, zinc, rubber, and chemicals of various kinds. The forest products industries cannot exist without the raw materials, manpower, equipment and supplies which are required for production. Some production equipment is now idle because of the lack of repair parts. Items like tractor tracks, pins, track shoes, ballbearings, and material for valves, where it is essential to have high heat-resisting metal, are already creating bottlenecks at tractor manufacturing plants. The same situation is affecting our ability to manufacture an adequate supply of power saws, sawteeth, band saws, in fact all types of saws, used in the production of both logs and lumber. If the demands of the defense agencies for forest products increase above our production rate of 1950, the industry will need a proportionally larger quantity of supplies. It is not anticipated that all demands for production equipment can be met on a current basis. This will cause the operators to face numerous production problems.

Measures to Alleviate Shortages

Some of these problems can be solved by more efficient use of what is available. One means of doing this is by using equipment a greater number of hours; another is by drawing upon equipment in other fields, such as farming or road construction, in off-seasons for those activities. In many instances, particularly in the South, Lake States, New England, and even the Middle West, farm trucks and tractors are used for winter logging. One of our main sources of off-season equipment capacity is in the road construction field. Producers should be encouraged to utilize this equipment, either by contracting their road construction or rental of the equipment, thus releasing their own trucks and tractors for actual logging. More attention will have to be given to the types of roads that are constructed, the speed of trucks, overloading, rotation of tires, and, as indicated above, the establishment of properly organized maintenance crews. Each operator should install an efficient and reliable equipment inspection service and currently make all needed minor repairs before they grow into replacement problems.

It is strongly recommended that every producer of raw materials such as logs, poles, bolts, etc., immediately inventory his equipment to determine his immediate requirements and what he anticipates will be required during 1951 and 1952 in order to maintain or increase his production. He also should carefully examine his operational programs and see what adjustments can be made to achieve better utilization of his capital equipment and supplies. Every operator should start now to lay out his road system for at least a year's operation and proceed as rapidly as possible to get these roads established so that they will have ample time for settling. Well graded and thoroughly settled roads will cut the cost of transportation, both in terms of dollars and cents and wear and tear on equipment. Each operator knows his own limitations; for that reason each operator will find it necessary to make his own evaluation, his own plans, and his own programs to cope with the shortages of both capital equipment, and of maintenance, repair and operating supplies that seem sure to come.

Discussion

Roswell D. Carpenter (So. Forest Experiment Station): Many of the small mills regularly operate on a part time basis. Is this considered in the 600,000 board feet average annual figure? Furthermore, isn't it true that a very large volume of logs are produced using farm equipment?

Mr. Holman: Much lumber is produced 100 percent by farm equipment.

It is realized that many of the portable and smaller permanent mills are inefficient in operation. However, it is also realized that these mills produce a substantial proportion of the national annual lumber production. Logging and milling equipment

must be available for these operators if present levels of production are to be maintained, and especially if an increase in production is demanded in the event of an emergency.

Fred R. MacDonald (Mountjoy Timber Co., Ltd.): What our company is interested in is finding sources of information on which we may draw for improving on our present methods. We might add that tractor equipment is the most critical shortage we are experiencing in the forests here. To date our company has been purchasing only one manufacturer's crawler equipment as well as stationery diesels, road graders, et cetera.

We can neither buy new equipment nor get parts for the equipment we have. We had a bulldozer held up for six weeks waiting for transmission gears, while agents claim that they tried to get the part from coast to coast. It appears that the company has not kept their parts department up with the volume of new machines sold. Now that we have considerable of their equipment we are almost obliged to continue because the other tractor companies hesitate to take in equipment on a trade because they realize that it is even harder for them to get the necessary parts for a competitive machine to put it in selling condition.

At times we are so discouraged that we feel we may have to go back to horses for a large part of the work now being done by machines.

Maybe Mr. Holman can do something? We understand the War Department in the States is carrying huge inventories of tractors of all types.

Charles Latimer (Nickey Brothers, Inc.): Has the National Production Authority developed any formal mechanism for acquainting operators with defense requirements and how to get government contracts?

W. Burdette Wilkins: Yes, the Government publishes pamphlets giving directions for obtaining Government Contracts. For instance, one is published under date of March, 1951, entitled "Selling to the Navy." The number is NAVEX OS P–548; it sells for 15 cents per copy; and it can be obtained by writing to the Government Printing Office, Washington 25, D. C. They also publish this same type of pamphlet for the other branches of the service. Information can be obtained from the above address. Stamps are not accepted.

Effect of the Defense Program on the Availability of Woodworking Equipment

RAY C. DUBRUCQ, *President, Association of Manufacturers of Woodworking Machinery, Vice-president, Crescent Machine Division, Rockwell Manufacturing Company*

Historical Background of Woodworking Machinery

THE question has been asked: "Where does woodworking machinery fit in the defense picture?"

This is not a new question. It was answered and answered well, during the World War II when the WPB at first believed that woodworking machinery was non-essential and granted the industry only a 40 percent materiel allocation, against 90 percent requirement. It took the Army, the Navy and the Air Force to convince the WPB that wood products were indispensable to the war effort.

The best answer, however, is to look at the part played by woodwork in the life of man, either in peacetimes or war periods. Wood has always played a major part in every phase of man's existence. It has sheltered man and given him every comfort demanded by advancing civilization. Its early usage was made possible through crude tools—history tells that story. Tools, however, were the means of converting trees to the finished product then and today.

Man has always looked for the easier way to do things and a steady improvement in tooling resulted. The modern implement for wood conversion is woodworking machinery.

The development of woodworking machinery was rapid and in line with all other developments of technical skills. The tremendous usage of wood products in the United States is shown clearly in current Department of Agriculture figures: 42 billion board feet each year; 49 percent for construction; 42 percent for boxes and crating; and 9 percent for fabrication.

All of these usages require some form of conversion by the application of woodworking machinery. The Department of Agriculture predicts a continued source of supply and a demand that will consume at least 39 billion feet in the year 1999. This is only a 7 percent reduction of current usage and with the proper consideration of yield will reach further into volume of finished products.

The woodworking machinery manufacturers have played an integral part in this yield, with the help of the woodworker and the tool manufacturer, through the development of efficient cutting tools and machinery. Most of this has been done during normal periods, as during wartime the pressure of production allowed little time for development. Postwar periods however, have always resulted in improvements.

The need for wood producing equipment is particularly acute during the limited hostilities we are engaged in today—hostilities which may flare up into full-scale war at any time. Throughout the last war period, 1942–1945, the demand of the defense program on woodworking machinery was 100 percent over the demand during the 1937–1942 period. From 1946 through 1949 it was 120 percent higher than through the World War II period, or 4½ times the average usage during the 1937–1942 period.

What does this point up? To me it shows that our production of woodworking machinery was so completely used up for defense work during World War II we were forced, through priority demand, to neglect normal users of woodworking machinery. They were forced to convert plants to defense, with very little normal wood products manufactured. With the end of the war and a total rescinding of priorities the machinery industry was flooded with orders to replace old machines and enable keeping up with production of factories that had benefited through new machinery allowed them by the priority system. This equipment was then converted from war work to normal wood products manufacturing.

Our experience in this regard should emphasize that the woodworking machinery industry is a most important one in peace as well as in war time, and, as the Department of Agriculture has stated, is "A key component in the economic recovery of a nation after war".

A summary of the usage of woodworking machinery during World War II would be in order now. It was indispensable to the production of war material, ships, tanks, planes and equipment for the transportation of guns, ammunitions, food, etc., to the Armed Forces, also to maintenance and repair to Army bases, to construction of barracks and defense housing and to many other essential defense purposes.

Woodworking machines had many and varied uses in War Production and were produced on prime and sub-contracts for the account of the Armed Services, including:

Department of the Navy
Marine Corps
U. S. Army Air Corps
U. S. Army (General)
U. S. Army (Ordinance)
U. S. Army Engineers Corps
Signal Corps
Maritime Commission
U. S. Treasury Dept.
Atomic Energy Commission

Production for War and Defense purposes ranged from 100 percent of individual plant facilities to 70 percent—with an average of 90 percent. Ratings ranged from AAA down, with high priorities predominating.

Prime contracts with the Armed Services accounted for a large portion of the industry's production. However, many sub-contracts were for machines to process materials for:

Aircraft
Ship construction
Gunstocks
Shell boxes
Gun boxes
Food and supply crates
Mess tables for barracks
Marine plywood for PT boats and Liberty Ships
Tanks
Camp buildings and hospitals
Furniture for Army and Navy Officers' quarters
Parachute drops
Litter carriers
Facilities for the armed forces in the Pacific
Mill work used in barracks
Radar parts
Submarine parts

Here are a few figures to emphasize the great usage of wood products in World War II.

In 1944 alone 50 million board feet of high quality wood were used in manufacturing Army rifle stocks. Every overseas soldier required 300 board feet of lumber to ship his initial supplies and then required 50 board feet per month to maintain him. It is believed this requirement still exists. A submarine chaser required 200,000 board feet of lumber for decking, bulkheads and trim.

The foregoing are only a few examples of extreme usage and each case required varied woodworking machinery operations.

A Look at Expanding Current Needs

The present period is causing an expanded demand for wood products and requires full capacity usage of woodworking machinery equal to that of World War II. But there still is sufficient manufacturing capacity to keep up with demands of normal usage. We are better prepared now to produce more equipment. Materials will be the key to this production and a continued drive is being made to secure recognition by government authorities to make these materials available to the industry.

I pointed out that we produced 100 percent more equipment during the years of 1946 to 1949 than was produced during the high war demand period of 1942–1946. This production capacity still exists and the industry is ready to be of "all out" service.

I have attempted to point out that woodworking machinery is a vital defense need. I have indicated that productive capacity of the manufacturers of woodworking machinery has grown sufficiently to equal a potential demand of defense requirements and also to absorb the demand of public welfare usage. The possibility of this production capacity being utilized depends upon the amount of material released to the industry, which leads to the subject of this paper, "Effect of the Defense Program on the Availability of Woodworking Equipment".

It is most important then that the woodworking industry should determine how far it can go in its varied production program. How far will the home building program be allowed to go? How far will the furniture industry be permitted to operate in its normal functions? These are problems that each of these industries must and is trying to determine.

A recent meeting of the Furniture Manufacturers' Advisory Committee in Washington indicates that it, too, is trying to make its plans. Permission of the entire group of woodworking industries to use their full capacity in a combination of defense work with their normal public welfare production would, perhaps, put the woodworking machinery industry to a supreme test. We believe that with proper government controls this can be accomplished. Our increased capacities will take care of both. The fact that wood product industry made such terrific demand on the machinery industry immediately after production restrictions were relieved from 1946 through 1949 is ample proof that it had been sorely neglected during the war period. We were unable to furnish any type of equipment to it, including much needed supplies such as drills, mortising bits, knives and saws. Many machines had been shipped to the Armed Services with sufficient supply of these essential tools to have outworn the machines. Saw tables with 24 rip saws and cross cut saws were not unusual. It is difficult to conceive the using up of these blades and the result, of course, was we had to deprive industry of their usage.

This was improper control of materials and should be definitely avoided during this period. An effort on the part of all branches of the wood industry, the machinery manufacturers and the tool manufacturers, to put pressure on government procurement officials to be reasonable about their requirements would undoubtedly permit proper dis-

tribution of these tools that would take care of all defense and normal requirements.

We all know too well how much of this equipment and many other types of equipment remained unused and was offered for sale after the last war, glutting the market and causing much unnecessary confusion. For a period, in some classes of equipment the "Used Dealer" became the source of supply of unused or new equipment and left the manufacturer of this equipment holding the bag. This can and should be avoided. Even though the lure of a large volume order for this equipment is attractive we should make every effort to avoid a repetition of that situation.

To summarize the foregoing, the increased capacity of our industry, the woodworking machinery manufacturers, can take care of the demand of the defense program and the public welfare program if reasonable and well planned controls permit us to do so.

Some Facts About the Industry and Its Products

This, I believe, is a suitable time to present some facts about the woodworking machinery industry itself—to point out its achievements in machinery design, keeping up with the trends and demands made upon it, and to show the task it had in offering its developments to the users of such equipment.

To cover each type of machine used in the industry and to follow its steady improvement would result in a long, tedious paper. Therefore, without considering individual manufacturers of certain types of machines, I will select the tenoner, the boring machine, the moulder and the surfacer as subjects. In discussing these several machines I hope that I can successfully prove that all woodworking machinery is highly developed through top engineering and of high quality through precision machining and construction.

The Surfacer

Using the surfacer as my first example, let us look at the planer of 25 or 30 years ago, or any period prior to the direct motor-driven application. Here we see an open framed, babbitt-bearing exposed-gear unit, designed even then to do precise work—although not so rapidly perhaps as today—but nevertheless excellent in design and construction.

In the modern machine we offer to the industry a sleek, high-production, low-cost operation unit that has incorporated in it engineering and precision construction which is equal to any equipment offered by any other industry. The modern planer, built in widths of 12 inches to 44 inches and equipped with cutter heads with from 3 to 8 knives will produce any grade of finish desired at feeds ranging from 25 to 100 feet per minute and over. Finger tip controls are provided to give exactly the desired rate of feed, dimension of finished stock, and quality of work. Such features as micro-feed selectors, precision thickness indicators, brakes and reverse feed controls, motor driven knife grinders and jointing attachments are part of the present day machine.

The most important factor, however, about a planer is the heart of the machine, the cutter-head. This rates special mention. A great deal is expected production-wise in quality and quantity of the planer. The cutter-head is the key to this accomplishment. Perhaps the most commonly used would be the 6-knife round 36-inch unit. At any rate I will use it as an example.

From a forging 50 inches to 60 inches long a 4 or 5 step turning with a maximum diameter of from 4½ to 6 inches is produced. This turning must be made with precision that guarantees the ultimate balance that is necessary. Grinding, drilling, milling and assembly operations follow—all with the ultimate, perfect balance, the No. 1 requisite.

The completed head is an assembly of a minimum of 79 separately machined parts, these parts consisting of 6 high-speed steel knives, 6 gibs, 66 gib screws, and the head-body itself. In addition, knife settings screws are furnished. This assembly must be so precise that at the basic speed of 3,600 rpm. each knife, through the proper application of grinding and jointing attachments, will take its equal part of the cut and produce finished lumber so smooth that the knife marks can only be seen on close inspection with proper lighting. This is true balance maintained through properly engineered support from the finest precision bearing and machine construction.

The proper feeding of the stock to this cutter-head must, of course, have been developed simultaneously. The chip breakers and feed rolls must be flexible to allow for the irregularities of rough lumber—designed to bring this lumber to the head with the least amount of strain or distortion to the material to permit the smooth and accurate cutting by the head.

A few years ago a prominent manufacturer guaranteed the thickness dimension and the quality of his planer work at the tail end of his machine. In this he showed his confidence in the machine to perform and produce the desired results, but he could not guarantee lumber's resistance to maintaining this dimension. It has often been said that "God made wood and only He could keep it straight".

The Tenoner

The double-end tenoner through the wide scope of usage indicates constant and careful engineering. Here is a machine that has eliminated the usage of many single operation machines to combine such operations as dove-tailing, sill-horning, dadoing, bevelling, sizing, tenoning, coping, relishing, shaping, mitering and many others. To this basic double cut-off and tenoning machine have been added jump-dado attachments, scoring saw units, cam-

operated shaping attachments and others to such a degree of synchronized operation that 2, 4, 6 or even 8 separate operations can be performed in the single passing of stock through the machine.

The same precision in construction, the same balance of rapidly revolving parts that have been built into other types of woodworking machines, are demonstrated in every operation of the tenoner. Easy approach to the cutting units by the stock is accomplished through highly developed feed chains, with cushion hold-down pressure beams, that guarantee product so accurately machined that fitting of component parts becomes matter of fact. Accurate variable feed drives, dial controlled adjustment for spread of beam and every facility for quick and accurate adjustment being provided. One look at the cam-action provided for shaping operation and jump-dado operation will indicate the untiring engineering feats put into this machine. It is a true achievement of the industry.

It might be well to stress at this point that everything mechanical that is required to properly adjust and maintain the adjustment to secure the fullest quality production results is provided, but the complete usability of the machine, whether it be planer, moulder or tenoner, depends entirely on the men who operate these machines. There is nothing to confuse the operator. The manufacturer of this equipment, however, has had a long, constant struggle to educate these operators sufficiently to maximum effective usage. Many of our top production woodworkers will nod to the woodworking machinery manufacturer for the benefits he has received through this effort to educate. It has only been through cooperation of both parties that some of the top production woodworking plants have been developed. These plants saw the capital return benefits of top production machinery and made it difficult for the people who would not plow profits back into their business. Many plants today are still operating with machines that should have been in the "cupola" years ago.

I want to quote one of the top successes of the furniture industry: "The replacement of worn machinery, or machinery which is outdated by technological improvements, is as vital to a woodworking manufacturer, if he expects to stay in business, as air and food are to a human being. Any manufacturer who fails to realize this fact over a relatively short period of years and gobbles earnings into dividends will find himself in the same position that so many did in about 1932, when they were forced to meet tough competition and found themselves unable to, because of antiquated, uneconomical machinery, and because of their lack of foresight were forced out of business".

The Moulder

The moulder is an outstanding example of development. With it let us consider the planer and matcher. As you know they are similar in operation and basic principles.

The product of the moulder is common to all of us, but the speeds and the accuracy of detail might not be too well known or appreciated by some of us. Have you ever watched a high speed moulder being fed stock, semi-dimensioned at one end and then seen the 2, 4, 6 or 8 multiple cut mouldings popping out at the other end—each with perfect details at speeds of 75, 100, 125 feet per minute and higher? If you have, have you thought of the terrific amount of stock that had been cut away, chips disposed of, and how this was accomplished?

Or have you watched a high speed planer and matcher dress, tongue and groove and hollow-back a board at 200 to 300 feet per minute and higher?

In these operations I believe we have reached the limit of wood's resistance to breakage. We do have this limitation to consider for there is a tremendous resistance to the power feed of these machines developed by the 4, 5 or 6 cutter-heads, each taking its part of the cut, and the friction of guides and hold-downs. Here the design and relation of feed rolls, chip breakers, hold-downs, guides and the bed of the machine play that important part of forcing and guiding the stock through the cutterheads and maintaining the "one-piece" condition of the finished stock. To appreciate this strain you would have to see a board "explode" during an operation. There are other limitations. Manual handling of stock is one of them. Selection and grading of stock is a second. Hopper feed attachments and take-away conveyors have eased the handling. All these attachments have been highly developed.

The moulder and the planer and matcher are grand examples of woodworking machinery development. Here again all the necessary control of adjustments is provided. Cutterheads are run at speeds that vary from 3,600 rpm. developed by standard frequency up to 7,200 rpm. through the use of high frequency and in some cases variable speed, short-coupled, belt drives. Each approached to the problem having its individual merit and each the result of much planning and hard work.

The Boring Machine

The boring machine with its multiple drilling operations, producing multiple holes in wide or close spacings, through adjustable, flexible spindle drives and even through closely spaced clusters and with the adoption of hydraulic feeds permitting constant steady feeding of the stock to the drills, is an accomplishment that we are especially proud of.

I could go on to the drum sanders, belt sanders, spindle sanders and the disc sanders, and show the results of development in their ability to produce a velvet finish that is the present day demand.

I could mention the lathe that has been developed to produce 6, 8 or 10 turnings per minute—round or multi-sided—perfect, complete turnings.

Think of the high productivity of the modern band saws, rip saws, resaws—single, double, vertical and horizontal—engineered to use a minimum of saw kerf.

Consider the shaper, developed to the automatic stage with tremendous savings in labor and material costs.

Consider the straight-line rip saw developed to permit the gluing up of stock from the saw, with the engineers having constantly in mind the elimination of waste produced by the older methods. This is indeed a development beyond the appreciation of the woodworker, since it took a lot of selling to reach the full scope of usage it now enjoys. Having sold this type of equipment I could cite cases where it took many days of selling to convince the prospect that this method was a quick cost saver because of the time and material saving possibilities.

The Industry Will Do Its Part

Let's get back to the topic. There is no question that victories in war time are won through the ability of the victor to have supplied on time the needs of the men at the front. This credit lies with the developer and the producer of these needed materiels. It can be ammunition, transportation, or the comforts needed by the men who fight.

We, in the woodworking industry, have performed a potent part in the accomplishment of victory in all of our wars, and we feel that we will be even more important in this present period of defense or war. Through the combined efforts of all of us involved in the industry, from tree to finished product, and with a well planned control of timber usage and sufficient grant of all materiels needed, we can and will be able to take care of all requirements for war and public welfare.

I would like to close with an expression of my appreciation and respect for the founders of the woodworking machinery manufacturing industry which I represent, and to all the men who have participated in the industry's development and to state that I am highly honored to serve as their Association president.

Discussion

R. M. McFarland (Wood Magazine): To what extent will the woodworking industry go into production of other war or defense products during the present period?

Mr. DuBrucq: That question cannot be answered at this time. It is, however, correct to assume that if materials for woodworking machinery are not available or that the demand for the equipment does not hold up, the industry will go into other fields. Some have done so already. The capacity of production in the industry has increased and as of today the demand has lowered. The individual manufacturer is going to utilize his own capacity on some product and in the end if this condition continues the industry might not be able to supply an increasing demand for woodworking machinery. It could repeat the conditions that existed during World War II.

R. A. Hertzler (Southeastern Forest Experiment Station): What do the woodworking machinery manufacturers think of what the Forest Products Research Society is doing; and how can it assist these manufacturers in improving the fabrication of wood products?

Mr. DuBrucq: The woodworking machinery manufacturers are favorably impressed with the purpose of the Society. Too little cooperative attention has been given to the problems of wood fabrication in the past. The Forest Products Research Society becomes a medium through which a great deal of development and improvement can result. Its policies and approach were not too clearly understood at the beginning but the last few years have done a lot toward bringing the Society closer to the wood products producer and the machinery manufacturer, I believe, from here on in a great deal more will be accomplished.

G. A. Johnson (Mattison Machine Works): The effort of creating a better understanding of mechanical possibilities between machine manufacturer and fabricator of wood products is very valuable. The development of new uses for wood products by research also opens a wider field to woodworking machinery of established design and creation of new and better equipment.

C. Arthur Bruce (E. L. Bruce Company): Do you think the woodworking machinery industry is using the arm of research for the development of new equipment?

Mr. DuBrucq: The industry is cooperating with research organizations in an effort to develop new equipment and standardization of tools, and safety. These are all long-time projects and it often seems that little progress is being made. More general interest should be shown by all.

Mr. Johnson: The electronic gluer is one of the latest developments resulting from research by wood products and electrical engineers which resulted in the manufacture of new woodworking machinery.

Mr. X: What percentage of present woodworking machinery now in use would be considered as modern?

Mr. DuBrucq: A recent survey shows that less than 35 percent of the machinery in use is modern but about 75 percent of wood fabrication is done on modern machinery. This points out clearly that in most cases the old machine should be scrapped.

Davis R. Godwin (Atlantic Plywood Corporation): What scope of the industry does your association represent?

Mr. DuBrucq: Our Association represents (in volume) more than 75 percent of the industry as classified manufacturers of woodworking machinery. A recent listing of manufacturers claiming woodworking machinery as a product in their CMP applications totals over 225. Our membership is about 25 percent of that number.

Mr. Godwin: If the situation grows from bad to worse, will the efficiency rating of the individual firm be used as a basis in determining the availability of maintenance and repair parts?

Mr. DuBrucq: The industry has maintained a good record of repair parts and supply service and it will continue to do so. Material allocations alone can control this service. If a proper balance of these parts is maintained in government agencies procurement there should be no shortage of material for maintenance and repairs.

Mr. X: Do you think the present National Production Authority control will work better than the War Production Board control did, and why?

Mr. DuBrucq: Yes. NPA is manned with more efficient personnel. A lot of "Know how" was returned from industry to NPA ranks. Mr. Wilson is an example of the high caliber men now in NPA. Also such men as Mr. C. Arthur Bruce will aid industry by injecting their practical views into NPA policies and help see to it that they are carried out.

It is very evident that controls are not functioning properly at this time but it might be a lot worse but for the better-grade men trying to work out the problems.

B. C. Williams (Norfolk Naval Shipyard): What consideration is given by the manufacturer to keep equipment from being so pretty but more practical?

Mr. DuBrucq: The industry has not dressed up its product but has improved production by tooling and in doing so have put a few lines in the design.

The woodworking machinery industry owes no apologies for the practicability of its offerings, for its prices.

Importance of Wood in the Mobilization Program

C. ARTHUR BRUCE, *Director, Lumber and Wood Products Division, National Production Authority*

Introduction

TO ARRIVE at a clear understanding of the position of wood in the Mobilization Program it seems logical to look at that program. Of particular interest in this connection is its scope and its objective.

You are aware of course that the program is undertaken under mandate of Federal Law. The Defense Production Act of 1950—enacted September 8, 1950. It is safe to assume that only a small percent of our citizens have seen a copy of this law, and fewer still have read it. As to the scope and objective of the Act, the preamble entitled "Declaration of Policy" is very revealing.

> "It is the policy of the United States to oppose acts of aggression and to promote peace by insuring respect for world law and the peaceful settlement of differences among nations. To that end this Government is pledged to support collective action through the United Nations and through regional arrangements for mutual defense in conformity with the Charter of the United Nations. The United States is determined to develop and maintain whatever military and economic strength is found to be necessary to carry out this purpose. Under present circumstances, this task requires diversion of certain materials and facilities from civilian use to military and related purposes. It requires expansion of productive facilities beyond the levels needed to meet the civilian demand. In order that this diversion and expansion may proceed at once, and that the national economy may be maintained with the maximum effectiveness and the least hardship, normal civilian production and purchases must be curtailed and redirected.
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> "It is the objective of this Act to provide the President with authority to accomplish these adjustments in the operation of the economy. It is the intention of the Congress that the President shall use the powers conferred by this Act to promote the national defense, by meeting, promptly and effectively, the requirements of military programs in support of our national security and foreign policy objectives, and by preventing undue strains and dislocations upon wages, prices, and production or distribution of materials for civilian use, within the framework, as far as practicable, of the American system of competitive enterprise."

Scope and Objective

This declaration of policy clearly reveals that our Mobilization Program has as its scope and objective not merely the strengthening of the military might of the United States of America to the point of effective opposition to acts of aggression on our country, but it is a mutual defense pact under the United Nations to support collective action thereunder in line with our foreign policy objectives.

The Mobilization Program is indeed a huge one and one which frankly is so big that it is hard to comprehend in its scope and impact on our economy. But there it is and we are already well on the road towards driving the program into high gear. Partial mobilization only is being undertaken now and broadly viewed the great debate of today as it relates to mobilization may be said to revolve around questions of how much and where.

As the tempo of mobilization increases wood becomes spotlighted as of greater and greater importance. A single rather dramatic reference to wood in World War II,—it is estimated, and I believe accurately, that in 1944 when we were in the thick of greatest intensity of the war, for every pound of steel expended a corresponding pound of wood was expended. During the first three years of that war direct military took approximately one half our entire available supply of lumber from production and inventory in the hands of the lumber manufacturers and their distributors, wholesale and retail. Approximately one half of the balance went to indirect military, and the balance, or one quarter of the total, to essential civilian use. The term indirect military included wood for housing, furniture, etc. of civilian war workers; wood needed by the farmer in his percentage of production of food and other products, for the military. Essential civilian use included wood for repair and maintenance of railroads and other transportation, utilities, public works, and agriculture in general. The god of war is truly voracious in his consumption of wood.

Perhaps I should at this point explain that the term wood as used in this paper, does not include wood pulp, nor its end products of paper, paperboard, nor the end-use of wood fibre for wallboard, insulating board or blanket material, or production of rayon and other synthetic or plastic products. All of these products in varying degree are used in a war effort, and are important in any of them.

How would we in Government service get along for example without plenty of paper? These uses account for about 15 percent of the product harvested from our forest lands. Their war story can be told more capably by those who know the part they play. I am quite ignorant on that score.

I am talking about lumber and wood products which make up the other 85 percent of harvest from our forests. This area just about parallels the jurisdiction of the Lumber & Wood Products Division of the National Production Authority and this Defense Agency is for all practical purposes the War Production Board of World War II. It includes lumber, rough and finished, millwork, veneer and plywood, flooring ties, posts, piling, poles, mine timbers and so on, with finished wood products such as shoe lasts, battery separators, picker sticks, and innumerable large and small articles of wood. With respect to some articles such as wood containers and furniture it is inclusive of the wood material used for manufacture but not the end product. Altho as a generalization it may be stated that lumber contribution to war is the same as its contribution to peacetime civilian needs, some of these items are very important in war and draw on our forest resources much heavier than in normal times. For example it is estimated that in the first year after declaration of war we would require in excess of 5,000,000 poles, 75,000,000 lineal feet of piling, several hundred million crossties, etc.

If armed conflict should come—and let us all hope that we will become so strong as to prevent another world war,—it would apparently require shipment from our shores. In World War II it is estimated that one third of that expended pound of wood for each pound of steel, went into boxes, crates, dunnage, skids, pallets, etc. There was an average of over 150,000 feet of shipping material made of wood on each vessel sailing from our shores.

The answer to woods importance lies partly in the fact that wood has proved its case in the game of war. That game is a rough game, and wood has proved it can take it. When used for containers for overseas shipment, these containers whether made of tin, plastics, paper or paperboard, must seek the final protective cover of wood. When there must be elimination of steel parts as a conservative measure, wood of sufficient structural strength is the substitute and usually the only one available.

Timber Supply

Can wood measure up to the demands that may be made on it? Do we have the timber supply? Do we have the plant to convert? Can that plant operate satisfactorily under war conditions? In closing this paper I want to discuss these questions, and also point to you for some of the answers. I assume I have brought home to you the importance of wood in our Mobilization Program. But because the purpose of this paper is to emphasize that importance I call your attention to the fact that wood went to war in World War II as the principal raw product of over 1200 different items. These ranged from prefabricated houses, barges, small boats, aircraft and truck bodies to cabinets, chests, furniture, lockers and caskets and on down the line to tent poles and pins. All of these items may be made of steel, are made of steel and sometimes aluminum. But on the entire list to what other material than wood may we turn, when metals require strict conservation?

Do we have in this country a timber supply to meet the potential war demand? From the standpoint of quantity the answer is yes. The latest Forest Service figures indicate there is an excess of one billion six hundred million board feet of standing timber. The ratio between saw timber removal and growth has declined from an estimate of 5.8–1 in 1918 to 1.53–1 in 1944, and today for all practical purposes we are in balance. While we cannot draw excessively on our reserves without impairment of Governmental and private forest programs looking towards balance of drain and growth, if we need the timber for a war effort too much attention cannot be paid to such impairment. Of course this is true of all of our other natural resources, such as metals, oil, etc. We do not like the waste of war but it would have to be faced and it could not be avoided if war comes. The reserves of timber on our public domain should carry its share of the load. These reserves did not carry a proportionate burden in the last war.

In considering supply we must, of course, give attention to the woods that may be imported into our country or such foreign woods as might be made to serve in a war effort without processing in this country. The importation of foreign woods has become a major factor in the wood using industries in the United States. In fact we have developed into an inporting country rather than an exporting country within the last decade. These imported woods are serving certain industries such as the furniture industry, and it is safe to say that there are today more than 100 species which are being used by the furniture industry, the principal species, of course, being mahogany. In 1950 we had an all time high in imports. The trend in 1950 was from 10.3 imports to 1.0 exports. During World War II the principal foreign woods used for the war effort were mahogany, balsa, teak, and rattan—mahogany for aircraft and boat building, balsa for aircraft and floats, teak for boat decking, and rattan for boat fenders. All of these species are again entering into the mobilization picture and we can assume that they will become more important as the program builds up.

Conversion Facilities

It is in these areas of special woods for special use, both domestic and foreign, that critical shortages may lie. This is the area in which you con-

cerned with research can be and should be very helpful. When a species becomes in critical supply, substitutes must be found, and the same is true in the substitution of grades.

Does the lumber and wood products industry have the plant to produce what is required? Fortunately the industry has no conversion problem at the moment. By and large the products needed for defense are the products needed for peace. This plant of ours is greatly divided in ownership, it being estimated that there are 60 to 65 thousand full or part time sawmills, almost un-numbered finishing shops and with 1,500 wholesale distributors and 25,000 retailers. The largest company in the country has never shipped more than a small percentage of the total number of products.

In 1945 it was estimated that there were 5,500 of what might be termed the major mills and these mills produced 77 percent of the total production, that there were 4,500 medium sized to small mills which produced 11 percent of the total production, the balance of 12 percent being what might be termed "in and outers". In peacetime the only limiting factors on lumber production are markets and prices. In war time the limiting factors on production are skilled manpower, equipment and supplies. In World War II lumber was in short supply as follows:

1942	17 percent
1943	12 percent
1944	7 percent
1945	9 percent

At the start of World War II we had an inventory of 17 billion, today we have between 11 and 12 billion.

Presently lumber production is about at its peak for all time. The problem is to maintain that production because, if war should come, all lumber produced could be used to advantage. One of the purposes of the Lumber and Wood Products Division of the National Production Authority is to obtain the necessary steel and other critical metals and materials without which the lumber industry cannot operate. To do this we are confronted with a real task in education as to the important part that lumber plays in mobilization, and the necessity of supplying the industry with the steel for saws and other operating supplies necessary in forest and plant. Further than this, to develop ways and means where we may not lose our manpower and skilled workers to other industries where the work is less arduous and the pay and other conditions more attractive. In other words, we must be a claimant for manpower to avoid repetition of shortages which are bound to occur otherwise. We manufacture a natural raw product which due to the nature of the manufacture does not lend itself to the mechanication of other industries and which on the other hand requires more manhours of labor per unit of production than almost any other industry.

Research Plays Its Part

You gentlemen are interested in research in the wood field. To my mind the present conditions confront you with a challenge and an opportunity. I remember way back there when Mr. Axel Oxholm was connected with the Department of Commerce and I happened to be a member of his Wood Waste Utilization Committee. Mr. Oxholm, I believe, was instrumental in bringing to this country certain Swedish patents on timber connectors. The use of lumber in place of structural steel is aided by these connectors. One striking World War II example of steel conservation, made possible by the use of timber connectors, was a Navy blimp hanger 1,000 feet long, 153 feet high and with a roof span of 237 feet. Two thousand and fifty tons of structural steel would have been required. Wood was used in its place at a cost of 200 tons of steel used to fabricate the connectors.

Broadly speaking TECO connectors and TECO TRIP-L-GRIP Anchors serve as a reinforcing member to wood. It is my firm conviction that the use of steel in reinforcement of wood is in its infancy. I believe that structural members can be developed where wood is combined with steel which will save not only wood but also steel. When concrete became reinforced it ushered in a new day in that industry. Reinforced concrete was actually a new product. Reinforced lumber may be a dream but if it is to came true you men of research are the ones who will develop it.

The fact that the Forest Products Research Society is only a few years old, and has achieved a surprising stature in a short period of time, is, I believe, evidence of the multitude of opportunities for practical product development in wood. These opportunities are a challenge to you as an integral part of our great lumber industry. By and large the lumber industry knows too little yet in a scientific way about its product and what may be done with it so that it may better serve the public. In this research field the lumber industry will of necessity have to utilize scientifically trained minds and minds that are not hampered by the traditional attitude of the industry. Minds in fact which, without this handicap of traditional attitude, do not know that it cannot be done, and go ahead and do it.

Summary

We of the lumber industry face many problems. With the rest of the world struggling with governments many of which are shattered and with industry disrupted—all other nations apparently however counting on a strong and vigorous economy in the United States to help put them through, America is now striving by production to keep its own economy in order, so that we may withstand abnormal demands thereon. To do so it is essential in

my opinion that Government assist the lumber industry to produce to the utmost. And this frankly is the policy of the Division which I now head.

I hope in closing that I have driven home the fact that lumber and wood products are extremely important in the defense effort. In driving that fact home I hope that I may have stimulated you to render individually and collectively thru the Forest Products Research Society all of the assistance that you can give in putting your shoulders to the wheel, your research shoulders and otherwise, to the end that lumber may continue to serve as we know it will be expected to serve in our mobilization program.

Discussion

John G. Kuenzel (Bureau of Ships, Navy Department): Is there a National Production Authority list of the end uses of wood, and, if so, where can it be obtained?

Mr. Bruce: There is no N. P. A. list of the end-uses of wood but there are a number of such lists available. Two of these are as follows:

1. Industrial uses of selected timber species. Industrial Series No. 69 U. S. Department of Commerce U. S. Government Printing Office, 25 cents
2. Wood used in Manufacture, 1948. Forest Resource Report No. 2, Forest Service, U. S. Department of Agriculture, May, 1951. Free

The Conservation Section of the Lumber and Wood Products Division is preparing comprehensive bibliographies on various phases of wood utilization, particularly the utilization of wood waste. These will be available soon.

Richard K. Speairs, Jr. (Department of Biology, Centenary College): Does the act of September, 1950 (NPA) as referred to in your paper apply to the timber producer?

Mr. Bruce: Yes. But it should be recognized that while the Defense Production Act of 1950 authorizes governmental regulation of the timber producer, N. P. A. has not as yet exercised this right.

Mr. Speairs: Can the NPA order a farmer to cut his timber if it is wanted in the defense effort?

Mr. Bruce: Yes. However, the answer to this question, as well as the previous one, should be regarded as my opinion of the basic authority of the Act. Such opinion is in a sense legal and it might well be that a farmer ordered by NPA to cut his timber could locate counsel who would resist such action on a legal basis.

Frank T. Parrish: You mentioned the procurement of wooden truck bodies as in the last war. Did you say that there is some procurement of truck bodies at the present time? For what purposes and to what extent?

Mr. Bruce: So far as I know the military has not purchased any wooden truck bodies in the present defense effort. Such purchase would seem desirable because; (a) the military has historically turned to wood (hardwoods) when steel becomes in short supply, (b) the supply of steel is diminishing rapidly as the rearmament program gets into higher gear, (c) the lumber used is thick stock requiring a long period of seasoning, and production of this material by sawmills will start as soon as orders are placed, and finally, (d) detail of specifications and inspection can only be worked out satisfactorily on actual placed orders.

James S. Bethel (N. C. State College): You mentioned the need for information which would make it possible to develop substitutes for scarce items such as high grade white oak. Is any effort being made to insure that military agencies will take advantage of this information and conserve the high grade wood to prevent its use where inferior grades would serve?

Mr. Bruce: A continuous effort is being made by National Production Authority to the end indicated, and its relationship to the military in this field is at present excellent.

"Mobilization Requirements for Technical Men in the Woodworking Industry"

C. D. DOSKER, *President, Gamble Brothers, Inc., Louisville, Kentucky*

THE natural inclination of Americans today, as a people, are those of peaceful pursuits in industry. We live in a land rich in resources, and from those resources we have built a standard of living for our people that is unequaled in recorded history. We seek to rule no other lands or peoples.

New Era in American Living

The present mobilization for defense, therefore, comes as a severe shock to the average American citizen. He does not understand why after fighting, and presumably winning, two wars in order that the world may be a safe place for free people he is now called upon to adjust his living standards and thinking to the preparation for a possible Third World War. The average American does not understand the world conflict of ideologies. Furthermore, he does not want to take time to study their effect upon our country, or on him as an individual.

The average citizen wants to build homes, furniture, television and radio receivers, refrigerators, washing machines, automobiles and all the rest of those gadgets that make for a more pleasant and comfortable living. In fact, he is too busy in these pursuits to realize that the price of freedom is eternal vigilance.

Had he been more conscious of his freedom, had he stopped to think, he would have realized that World War II has really never ended. Had he been less in a hurry to urge demobilization of our armed forces, to dismantle our war plants, and to dispose of surplus munitions of war at a scandalous economic loss to the nation, his son, or his younger brother, would not now be preparing to don a uniform.

Since Korea there has been a gradual awakening, a consciousness on the part of the people of this nation of ours that things are not well in the world, that it is a sick world, a confused world, and a world in which currently "might makes right". We must, therefore, from sheer necessity as a safeguard to our freedom create those things which make for national strength. We know from past history that only the strong may remain free.

We have, therefore, approached a new era in American living, an era in which we must live as the nations of Europe have lived for centuries, in an armed camp, prepared and ready to strike back on a moments notice to maintain our freedom.

We are facing the problems of the lack of international understanding that have led to most of the wars in history, international greed for power, both economic and geographic, and the desire to control and to stifle the freedoms of others is rampant in the world.

We have not yet become used to this new situation in which war may come tomorrow or it may not come at all. We are facing a situation that may last for a decade, or more, and we must, therefore, prepare ourselves mentally to live in such a world. We must be realistic, for to be otherwise is to court disaster.

Industry Must Awaken

I will not attempt to discuss all of the legislation that has been passed concerning the problem of national defense. Let me suffice it to say that we have returned to an era of a more or less controlled economy and alphabetical bureaucratic agencies.

I frequently wonder what has become of the reams of paper and the hours of work of those earnest men who so arduously undertook to analyze the errors of policies and procedures during World War II in order that we might avoid them in the future. The files of the National Security Resources Board have apparently been forgotten.

In undertaking the problems of preparedness, industry itself must awaken to the fact that the principal problem is one of vital individual initiative of the management of each company. We must not think of preparedness and mobilization as a largess that will mean business for all. There is a great deal of difference between the preparation of a nation to defend itself in anticipation of a war and production for war.

In the case of preparation there are many nonrecurring items. In the case of preparedness, we are simply building up and putting into a stock pile those items which are essential to the maintenance of a military force capable of striking on immediate notice. It means that adequate reserve supplies are essential for maintaining this force.

In an all-out production effort for war there is constant production of munitions to sustain the Armed Forces. Herein lies the difference.

Each business organization should have its own M-Day plan prepared and ready in the event that a shooting war should develop. Such a plan must be based on the past experience of management and should classify those items which each manufacturing concern believes that it can manufacture to the best advantage for the good of the nation.

I am sure the question that will be raised, "Well, what do they want?" It is a good question but to find that answer you must seek out the information. Practically every item required for military use is catalogued by the various branches of the military services. You cannot expect the military to seek you out. There are many thousands of manufacturing establishments in the country. The military does not know what you can manufacture to best advantage, and only you can give that answer. Therefore, it must be your responsibility to put yourself on record with the various military procurement offices for your own good and the good of the nation.

I would like to recommend that during the current defense production each concern endeavor to obtain copies of the specifications covering the military items which in time of war you feel you could best produce. Study over the requirements of these specifications in order that you may plan on how you would handle them in production. I recognize that many of us will disagree with some of the provisions of these specifications, but we in turn should recognize that practically every military specification covering the production of munitions of war have been thoroughly tested to meet combat needs.

If through technology you feel that you can make it better, as a manufacturing concern it is your obligation to discuss this matter with the military, but if your ideas are turned down, remember that there may be other factors involved. A change in a military specification involves the problems of obsolescence in regard to material on hand and many other problems. All of these must be weighed before a change can be made.

The Importance of Wood in National Defense

It has been stated that in terms of tonnage of raw materials necessary, wood was second only to steel in the war economy of our nation in World War II. I do not know how these figures were arrived at, but we know that in terms of footage of lumber consumption, as a nation, we were converting between thirty-five and forty billions of board feet of lumber a year. If this were computed at the average of three and one-half pounds per board foot, air dried, this would be equivalent to more than sixty million tons of lumber a year. If added to this, in terms of tonnage, were poles, piles, ties, mine timbers, and plywood, it is easily understandable that the total might even be doubled.

This Society and the forest products industry are well aware of the toll which World War II took from our forest resources. We must recognize that the period into which we are entering is a period of uncertain duration. Knowing the importance of wood to our national economy, especially in times of war, it is therefore most important, in the interest of national defense, that every effort be made to obtain maximum utilization from every tree converted. It is my opinion that this industry and this Society must make a concentrated effort to increase the yield in terms of end products from our forest by a minimum of ten percent. This will require much technological assistance.

The effect of this increased yield can well mean the sustaining of plants producing products so essential to maintain a civilian economy. This increase in yield can well be the determining factor by which hundreds of plants in the wood-consuming industry may continue to operate.

Technical Aids to Increased Utilization

It may well be asked, "How do we proceed to accomplish this increase in utilization?" Well, I do not think it can be done over night. From the standpoint of our schools and colleges and from the standpoint of industry it means the training of hundreds of technical people. One of the first and most important points is that of training *men who can look at a tree and think of that tree in terms of end products.*

In certain species of timber this is comparatively simple. In other species, where end use is varied, it means that trees must be classified in the first instance for proper primary conversion. How will this tree or portions of it be used? Will it go into veneer? Will it go into lumber? Will it go into poles or piling? Will it go into railroad ties, or will it go into pulpwood? To be able to so classify trees requires an intimate knowledge of end products; secondly, a knowledge of markets and current demands; thirdly, a knowledge of the industry converting those logs.

While this problem is not as severe or serious in a non-war economy, it becomes of far greater importance in a war economy when the demands for special grades and species for special military purposes severely complicate the end use problem.

This is not a training job that can be accomplished in a few months or even a few years. It requires first, basically a knowledge of wood and its conversion methods; secondly, a knowledge of markets. It probably is, therefore, easier to take men who have a knowledge of products and markets and train them in conversion methods for this use.

As I have said, we do not know the extent or the duration of the current emergency. It, therefore, behooves us to think now in terms of the future. If we can get five or ten percent more yield from each tree taken from the forest, we will have to grow trees and we will have to cut less timber.

I recognize that this is only part of the story. Before you can proceed the logger and timber owner must be convinced. They must be shown that it

means more dollars to them for the products of their timber. To properly do this means that we must begin wherever possible with tree-length logs. Whether the logs be bucked at the skidway or at the mill, they should be bucked under the supervision of personnel skilled in end use classification.

The next point on which we must concentrate is that step of primary conversion, whether the logs are broken down into end products by either a sawmill or a veneer mill. The other end uses are less critical.

In the case of sawing, every effort must be made to obtain the highest possible grade out-turn. By giving extreme care to sawing, edging, and trimming, much can be done to avoid manufacturing defects which presently, especially in the product of small mills, degrades so much lumber and prevents its use for the purpose intended. This point is one which the sawmill manufacturer himself can watch. Improve supervision.

There is a second and more important aspect of conversion. This is the mechanical aspect. Much of our lumber today is produced by circle mills. This is particularly true of all regions other than the far west. There is a great need today for an inexpensive band mill that can reduce a log into boards with much less kerf than that required by the circular saw. One-half of the ten percent saving that I am talking about can be accomplished by the mechanical improvement of the process of sawing alone. Starting with the circle mill and the edgers, sawkerf at these operations can be reduced. These two points require concentrated effort for mechanical improvement.

If this Forest Products Research Society would through resolution of its Board call upon sawmill machinery manufacturers and saw manufacturers indicating the need of this study, I am sure that answers could be found.

The problem of better manufacturing is not confined to lumber alone. The kerf problem does not exist in the veneer mill but the problem of accurate and smooth cutting does. I am sure that most of you have seen, as I have seen, rotary cut veneer so badly manufactured both as to rough cutting and uniformity as to be rendered practically useless. To the nation, this represents a waste that can be reduced. It takes a long time to grow a tree that will produce a good veneer log. It can be ruined in a matter of minutes. The answer to this problem is the closer attention to manufacturing details.

Here again lies the opportunity through improved mechanical methods of getting more veneer from each bolt cut. Stop and figure, if you will, what it would mean in terms of productive footage if through improved mechanical means another inch or two could be removed from the diameter of each veneer log before the core is taken from the lathe. To accomplish these savings requires serious study on the part of technically trained people who can study the problem and aid machinery manufacturers in providing an answer.

So far, I have dealt with primary conversion only. What happens after the logs are cut into boards, or the veneer peeled from the log? Millions of feet of lumber and veneer are wasted each year through careless seasoning or drying practices. While this is probably more pronounced in the lumber industry than it is in the veneer industry yet it occurs in both. Improper yard storage resulting in stain and doty lumber, lumber that is badly checked or warped and twisted, all result in unnecessary losses both to the manufacturer and to those who must use this lumber in secondary conversion. It is the problem of every manufacturer to study the causes of these problems and to train people to correct them by careful preparation of procedures to save the product.

As the product of the forests move into secondary conversion, we have the three-fold problem of material, men and machines.

I do not know how many plants in the United States using wood as a basic raw material convert 100,000 feet or more of rough lumber a month. I know this. It does not take a large plant to convert 100,000 feet of lumber in a month. If we assume that the value of this lumber, on an average, is $125.00 per M′ delivered to mill, kiln dried, I feel that we have taken a rather conservative figure. Many plants obtain only little better than 50 percent utility from the rough lumber which they convert. This may be caused either by use of the wrong grade of lumber or bad cutting practice. A little simple arithmetic will quickly show you the savings that would result if a plant obtaining 60 percent utility from its lumber could increase that yield by 5 percent to 65 percent utility. In cold hard dollars this saving would amount to $1,600 a month. Under these circumstances, how many plants could not afford to have a specially trained technician to supervise the cutting of their lumber. To do this job, an individual must know the grades of lumber and what each grade will yield in terms of length and width of cuttings when converted into rough blank sizes of the grade required.

Where do you get people who know the problem of lumber conversion? They are few and far between. The basic principles of proper conversion are well known. It is the problem of individual management to train personnel for this job according to the needs of his product. Here is a point also in which I believe every forestry school in the United States could cooperate by training students in the basic principles involved in the secondary conversion of lumber and veneer.

In regard to the problem of machines, we again face the problem of mechanical studies, studies having to do with design of saws, cutterheads and bits. This is not a problem that involves the individual manufacturer as much as it involves the machinery manufacturer, but it is a problem in which there is

real opportunity to improve utility by reducing to a minimum the machine tolerances required in the rough blank size.

I have previously said that the problems of the manufacturer is to study the specifications covering those items which he feels he can best produce for military use. Practically all specifications covering items for military production must of necessity involve quality control and sample testing. This is especially true in fabricated items requiring use of adhesives or finishes. As a manufacturer, when you have studied the specifications of products you would like to make, be sure to then proceed to train some person in your organization who can perform the necessary testing required by the specifications. If testing equipment is necessary and you do not have, or do not want to buy it, then arrangements should be made for some qualified concern or laboratory having the equipment do the testing for you.

Mobilization requirements for technical men in the wood industries is a problem for, by and large, the woodworking industry is still a non-technical industry.

I have outlined for you the needs for technical people. Their need is tied up primarily with improved utilization, which I consider to be of prime importance to national defense.

I have tried to deal with what I consider the important points at which technical improvement would be of great benefit to the industry both in times of emergency and in times of peace. I know of no way in which one could determine how many men are needed in each category. I do feel, however, that the most urgent need lies in the proper classification of trees for end use before the process of conversion is started. I know of no way to more quickly improve the utilization of our existing forests.

The need for technically trained men lies in every phase of wood conversion in the forest products industries. The pulp and paper industry has probably advanced far more technically than have the older and more established phases of forest products conversion.

There is one thing this Society should remember, it represents for the most part the technical know-how on which this industry must depend.

I think it would be well and I should like to recommend that the Board of Directors of this Society recommend to the Secretary of Defense that young men, who are graduates of either forestry schools or engineering schools and who have since graduation had experience in the woodworking industry, have their enlistment records so classified that they may be identified in the particular branch of service in which they are placed. I say this because in the case of extreme national emergency it may be well to organize within the Corps of Engineers a special group of Wood Technologists.

As I have said, wood is second only to steel in terms of tonnage needed for war use. The military can ill afford to ignore the services which these men might render in the handling, storing and using of wood within the Services themselves.

It also behooves industry to see that the military is cognizant of men going into military service from their plants who have special skills in such important functions of the forest products industry, such as the inspection of lumber, kiln drying of lumber, yarding of lumber, and milling operations.

We must remember that in times of war we are continually faced with a problem of changing of raw materials as shortages of these materials may occur. We should also remember that as war advances, in many cases, technical progress stops. You do not change horses in the middle of the stream.

One of the greatest problems that faces any nation in war is this problem of the freezing of technical advances.

Because as yet we are not in actual war, and in our hearts we hope it may not come, we must nevertheless be sure that those products required by the military that involve the use of forest products have full advantage of any technical developments we can provide while, as a nation, we are in a stage of military preparation.

Let me close by saying the need for technically trained people in the forest products industry in the event of war will far exceed the available manpower to fill the need.

Discussion

Harold E. Holman (National Products Authority): Does the Society wish to sponsor the analysis of the available man power?

Ed. R. Linn (Oklahoma A & M College): Efforts should be made to bring the right man to the right job whether they be young or old.

John G. Kuenzel (Bureau of Ships, Navy Department): Does the resolution propose to include both individuals, in and out of uniform, in the services in best assignment of man power?

J. Alfred Hall (Forest Products Laboratory): I just want to make a general comment regarding conservation. The paper has noted the need for conservation of wood in the process of utilization and of technical man power. This is highly important and necessary, but conservation in the wood-using industry is like a yardstick—it has two ends and the one is no more important than the other. One end lies in the forest; the other in wood utilization. The forest is the complex biological organism upon which the industry is dependent for its raw mate-

rial. It is not like a mine to be worked without thought of renewal, but can be made to meet the heavy demands of our mobilization program and at the same time remain as a permanent source of raw material. This will involve better cutting practices, good silviculture, correct forest management, and an adequate road system for opening up stands and areas which need cutting due to the condition of the stands. The forest must not be ignored in a wood conservation program.

Mr. X: How can industry be aroused to the importance of improved utilization of our forest resources as an aid to military defense?

C. D. Dosker (Gamble Brothers): It is difficult to arouse industry to the importance of improved utilization of our forest resources as an aid to national defense when they see a constant shifting of more and more products needed by the military to materials other than wood.

It is necessary to clarify the present situation by recognizing that preparation for defense is one thing and actual war conditions another. Many of the products now being made of metals or other materials would have to be produced in wood in case of actual war. I am afraid that as long as conditions exist as they do today it will be hard to convince the lumber industry of the importance of improved utilization.

Mr. X: Is it possible to classify logs for end use? A good example is the wood truck body program of World War II. The majority of the lumber required for this program, for the manufacture of sills, was between 83 and 89 inches in length. If all the logs had been cut into 8-foot lengths before sawing, practically the entire product of the log, including the No. 2 and even some 3A common boards could have been used for the purpose intended. Because standard length lumber was used, and no particular attention paid to the length of cutting, the utility of the lumber in conversion averaged less than 50 percent. These are the things that must be avoided. In a case of this kind, you can start with the tree and think of the logs to be cut in terms of the product to be made.

C. D. Dosker: Yes. It is possible to classify logs for end use and to avoid much of the waste in conversion of logs. Classification is a primary conversion problem.

Mr. X: Is it possible, within a reasonable space of time, to train men for the job of selection of logs for end use?

C. D. Dosker: I believe it is possible to train men for the job of selecting logs for end use. It is a job, however, that would require probably a year and a half of intensive training. In the secondary conversion of forest products it will be necessary first to make a breakdown into two groups—softwoods and hardwoods. These groups first would have to study the conversion of logs into their secondary products of lumber and veneer. They should be able to identify log types and the products which the logs provide. Two or three months of intensive training should give a man a pretty good idea of the external and visible defects on the surface of a tree and how those defects effect the product of that tree. It would then be necessary to study the use of these secondary products. In the case of softwoods their conversion in millwork plants, box plants, and other plants converting these secondary forest products into end products. In the case of hardwoods, the same would apply, although the problem is more difficult in hardwoods than in softwoods.

These men would then have to study potential markets for the various products into which lumber is manufactured. Market conditions would have a large effect on determining whether a log should go to a veneer mill or a sawmill. This would be especially true when the logs are of such character as to be border-line in quality.

This is an over-all problem of the forest products industries. It is a problem that involves the plywood manufacturers, the sawmills, the railroad tie manufacturers and the pulp manufacturers. We glibly talk of "Trees for Tomorrow", but we had better begin to think of how we are going to best utilize those trees, in order to make their growing most profitable. Second-growth timber presents major problems in conversion unless the timber is grown under the most ideal conditions.

Mr. X: What kind of a training program can be instituted in order that the small-mill operator may properly saw logs with improved precision to avoid waste in the mis-manufacture, and what type of agency should be charged with this responsibility?

Mr. Dosker: In order to organize a training program that will be popular with the small-mill operator, I believe it will be necessary to enlist the support of the State Foresters, the manufacturers of small circular saw mills, and the County Agents, backed by the various regional lumber producing agencies.

I do not believe that any man converting a tree into lumber mis-manufactures it deliberately. In many cases they do not have the money to properly maintain the sawing equipment and do not understand the importance "dollar-wise" of proper manufacture.

People generally fail to realize that the consumer of lumber does not buy boards by grades. He is buying utility and can afford to pay higher prices for a higher yield. Here again we have the problem of the lack of trained personnel to conduct instruction courses. These literally should be on a county basis in order to insure the attendance of the small-mill operators.

It is the responsibility of everyone interested in wood to see that better utilization is obtained from every tree converted.

Mr. X: What efforts can be undertaken to institute organized research in an effort to reduce saw kerf in the manufacture of lumber from logs?

C. D. Dosker: The wholehearted support of the manufacturers of saws and sawmill machinery is necessary to develop an organized program to improve the mechanical breakdown of logs into their byproducts.

I believe much can be accomplished to this end if a special meeting of the Forest Products Research Society and the machinery manufacturers were called in which all members of the Forest Products Research Society interested in this particular problem could participate. From such a meeting a programming committee could be set up which would organize a plan for doing the necessary research.

This should be a project jointly sponsored by the saw and machinery manufacturers and the lumber industry itself. It is to the advantage of all that improved methods, producing less waste, be developed.

Mr. X: What efforts can be made to insure better handling of small-mill lumber after manufacture to prevent stain and degrade due to warping and twisting?

C. D. Dosker: Much literature has been published on the handling of small-mill lumber to prevent stain and degrade after manufacture. The important thing is to get this information into the hands of the small-mill operator and see that he understands that it is to his advantage financially to take better care of his lumber both in manufacture and seasoning.

This is a joint effort in which I believe that State Foresters through their organizations and with the assistance of the County Agricultural Agents, as well as technical help of the United States Forest Service can be combined to produce results.

Mr. X: Should the forestry schools be charged with the responsibility for training both students and men from industry in the relatively simple operations of quality control and shear testing in gluing materials for military use?

C. D. Dosker: No, I do not believe that all Forestry Schools are qualified to be charged with the responsibility for training students and industrial personnel in quality control and shear testing of glued material for military use. Certain qualified schools should be selected, and short courses of probably one week's duration should be offered to industry representatives for training in quality control and testing. Quality control is not necessarily simple. It depends entirely upon the product being made.

It is also a responsibility of the military, especially the procuring agencies, to train inspectors for this purpose. It is in this category that men with previous training now in the military service should be selected for these important jobs.

TECHNICAL SESSION III—Tuesday, May 8, 1951, 2:00 P. M.

General Subject: Wood Utilization in the Defense Program

Chairman: George W. Trayer—Recorder: Jay M. Stevens

Lumber Conservation in Military Procurement and Container Design

J. A. SARGEANT, *Engineer Research and Development Laboratories, Fort Belvoir, Va.*

The purpose of this paper is to describe some of the measures that have been and are being taken by the Corps of Engineers as the lumber procurement agency of the Department of Defense to make effective use of and to conserve the available lumber supply. The author discusses the survey being made of military establishments to determine lumber needs and uses, proper requisitioning of species and grades, and specification limitations. Information is also included on the status of military specifications for boxes and crates and the development of new sheathed and unsheathed crates.

Introduction

THIS paper is presented by the author as a representative of the Engineer Research and Development Laboratories, Corps of Engineers, Department of the Army. As the major lumber procurement agency of the Department of Defense, the Corps of Engineers has a vital interest in, and a definite responsibility for the conservation of the available lumber supply. It is with this interest, and this responsibility in mind, that the following is submitted for your consideration.

Almost daily you find headlines and articles in the newspapers on iron and steel; the supply, the allocation and the shortages. In contrast, little is noted about wood except possibly as affecting the building industry. Nevertheless, wood is a critical war material. The public mind easily visualizes iron and steel in the form of tanks, guns, trucks and shells. Possibly because fighting is no longer done with bows and arrows, the place of wood as a munitions item is not so readily pictured. Even though its place is less dramatic, it is no less vital. Explosives, ammunition, guns, equipment and repair parts, and a host of other supply items must be shipped to the fighting front and to supporting bases behind the lines. This is where wood, or lumber, predominantly enters the picture as an essential material for the boxes, crates, pallets, kegs, and barrels required to handle, move and store the materiel. Without these, the more glamorous iron and steel would be useless. To further emphasize this importance of wood as a war material, it is interesting to note that during World War II a greater tonnage of lumber was used than of steel products.

Need creates demand. Where demand exceeds supply in wartime, critical situations result. It then becomes essential that the greatest possible use be made of available supply. This is no less desirable in peacetime in the interest of economy and the conservation of material resources.

Survey of Military Lumber Usage

Some time ago, the Corps of Engineers, in its procurement responsibility, initiated action in the interest of conservation and economy within the Defense Program. Utilizing the technical knowledge and experience of the U. S. Forest Products Laboratory, a survey is currently being conducted of all Department of Defense establishments which requisition and use lumber. The prime purpose of the survey is to determine quantity used, purpose for which used, and species, grades and sizes customarily requisitioned for these uses.

It is not the intention from the results of this survey to dictate to any individual user the kind, grade or size lumber to be used for any specific purpose. Each service is its own judge of such matters based on its functional responsibilities and the technical needs for carrying them out. It is anticipated, however, that a comparison of survey data and market conditions will bring to light reasons for any existing bottlenecks in lumber supply channels.

A further result hoped for from the survey is a means for education of personnel having requisitioning responsibility in the possibilities of broader use of the various wood species, use of lowest grades consistent with end requirements, and procurement of minimum and random sizes rather than fixed specific lengths and widths.

Means for Conservation of Lumber

Efficient and economical use of lumber supply can be accomplished in several ways, each of which is equally important:

Broadening of Requirements in Specifications

Efficient and economical use of available supply can be obtained by incorporating the broadest possible requirements in specifications. Such requirements are fundamentally based on design and end use of the item but even these do not ordinarily necessitate narrow limitations in the material to be used.

Species and Grades

Measures should be taken to insure that requisitions for lumber procurement set up requirements with respect to species, grades, and sizes that are as broad as are permissible under the specifications covering the end use of the lumber. As an example, if a container specification permits the use of lumber from several wood groups, the requisition should not limit the requirements to a single species, or two or three selected species, with such selection based on personal prejudices or preferences. This also applies to grades and sizes. Acceptance of the broadest possible selection of species, grades, and sizes assists the procurement office in filling the requisition most advantageously and economically under the current market conditions. This is particularly true with respect to relative locations of points of supply and delivery in the interest of short hauls.

Maximum use of the many species included in the various lumber groups should be permitted. A requirement should not be limited to oak when possibly any hardwood could serve the purpose, nor to pine when any Group I or Group II species might do. This similarly applies to grades or quality. Requirements should follow as closely as possible established commercial grades rather than include some restrictions necessitating a special selective grading unless there is some essential technical need therefor.

Sizes and Quality

Undoubtedly the most important means of conservation is to so design the end item or consider the end usage of the wood or lumber that excessive use or wastage is eliminated. This applies especially to items comprising numerous wooden members where it is very easy, and quite common practice, to use members all of one size, thickness, or quality. Care should be taken in design of such items that the various members are of sizes no larger than necessary to perform their particular function in the assembly. This feature of design is particularly important in connection with military usages where quantities involved may run to very high totals.

Care in Design

Probably the most effective means of achieving economy and conservation of lumber lies in applying intelligent engineering in design. There is much more to development of standard designs of wood shipping containers than having a draftsman draw some nice looking straight lines with a few dimensions around them and casual reference to "nominal" sizes. A lot of study and work is necessary, or should be. It is here that the packaging laboratories of the various Military Services, such as the Engineer Research and Development Laboratories at Fort Belvoir, Virginia are able to contribute answers to some of the innumerable factors involved in military supply which ultimately effects container requirements.

Comparatively few wooden containers, for military use, are procured and stocked in a standard range of sizes and types for general application to the packaging of any variety of supply items. It is true that several standard types of wooden containers, or partially wooden containers, have been designed and classified for use within certain weight ranges and for specific types of loads; but before even these standard type containers are selected and specific dimensions established, a lot of conditions must be looked into. Conditions both inside and outside the container affect the ultimate design details.

Those conditions from inside the container which most generally effect its size and type are primarily based on the nature of the contents: "Are they light and bulky? Fragile? Of heavy concentrated weight? Of heavy weight and extensive size? Are they loose items or prepackaged? Do they require cushioning, blocking and tie-down? Do they permit a tight pack or require clearance? Do they need protection against water, sand, mud, snow, wind, or pilferage?" Some of these are factors in the determination of an open or closed type of container.

Conditions to be met on the outside of the container cannot usually be exactly predetermined as ultimate destination is usually unknown. To be considered are: hazards of handling by hand, by fork lift, by ship, by grab hooks, by cargo nets or pushing and dragging with a tractor; hazards of transportation, which may be by truck, by rail, by ship, by airplane, by landing craft or even by mule pack; there may be periods of storage in the open, exposed to the elements, to extreme heat, extreme cold, extreme wet, dry or humid conditions, or cycling combinations of several of these. The boxed material may be neatly stacked in high lifts or hastily dumped in mixed piles.

With all the above facts to be considered, design for conservation of lumber would not appear to stand much chance for consideration, but it does. It is the very existance of all these conditions which must be met that brings about design study for the packaging of each specific item and the ultimate selection of the container which can be expected to give the necessary protection and also result in a conservation of lumber.

Practically all packing of military supplies and equipment is specification packing. This means that some packaging laboratory, military depot or manufacturer with military agency approval, has studied the item involved and selected the particular container needed to meet all pertinent conditions. Safe arrival in usable condition is a paramount military requirement but it is no reason why waste cannot be avoided.

Container Specifications

Specifications have been mentioned several times. These, like many of the laws of our land, are greatly disliked in some circles but, also like laws, serve to

establish certain levels of performance. A specification should not be looked upon as a necessary evil but rather as a tool required to produce a specific result; and, it is through specification requirements that most of the efforts toward conservation and economy can be put into effect.

In order to show action being taken in the Military Establishment and having a bearing on conservation of lumber, it is necessary to mention certain specifications common to all the services and currently in use covering the constructive requirements for several general purpose types of boxes and crates. These are well known to various suppliers of military supplies and equipment as well as to the box and crate industry.

JAN-P-105—Wood-cleated Plywood Boxes.
JAN-P-106—Nailed Wood Boxes.
JAN-B-107—Wirebound Wood Boxes.
JAN-P-104—Nailed Wood Sheathed Crates.
JAN-P-132—Nailed Wood Unsheathed Crates.

There are numerous other specifications covering containers partially of wood construction, or peculiar to some individual service or to some particular item and which cannot be considered as for general purpose use, so are not mentioned.

Now specifications, again like tools, must be maintained, kept sharp for effective use by revision to meet changing needs and conditions, new experience, data, or improvements in design. The specifications listed above are currently in such a process of improvement. The proposed changes and reasons therefor will be explained as of probable interest to those of you having contact with military supply.

Specification JAN-P-105, covering construction of Wood-Cleated Plywood Boxes, in itself is not being revised but will be benefited by revision now in process of Specification JAN-P-139 which covers Container Grade Plywood. The latter specification is being so changed that veneer requirements will more nearly conform to established commercial grades and thus avoid the need for a special grading to meet specification requirements.

Specification JAN-P-107, which covers construction of Wirebound Wood Boxes, is currently in process of revision by the Quartermaster Corps custodian to incorporate improvements proposed by the Wirebound Box Manufacturers' Association.

Specification JAN-P-106, for Nailed Wood Boxes, is currently in process of amendment to incorporate improvements and expansion of its field of use as explained later.

General Purpose Crates

The Corps of Engineers was assigned some time ago the custodianship and responsibility for development and maintenance of specifications for general purpose crates common to the various services of the Department of Defense. In carrying out this assignment, use has been made of the extensive test facilities of the Packaging Development Laboratory at Fort Belvoir, Virginia.

Prior to the assignment of the above responsibility, the Corps of Engineers had determined that certain inadequacies existed in the design of nailed wood boxes for contents, particularly of concentrated weight, or of large size, in the weight range between 500 and 1,000 pounds. Because of these deficiencies, such items were being packed in nailed wood sheathed crates (Specification JAN-P-104). A further determination had been made that the design requirements of the latter specification for weight of contents under 2,500 pounds were excessive and wasteful of lumber. As a result of these determinations, a project was set up to establish design requirements for the reinforcement of nailed wood boxes in the 500 to 1,000 pound range and for an intermediate nailed wood sheathed crate in the 500 to 3,000 pound range. This project has been completed.

The changes proposed in Specification JAN-P-106, resulting from this project, are specific requirements for the use under certain conditions of heavier bottom or floor boards and of additional battens and skids under items of concentrated weight which require bolting down or anchoring. This pertains especially to items for which clearance is desirable away from tops, sides and ends of a container. These changes will permit the use of such boxes rather than crates with the resultant saving of the major part of the lumber ordinarily used in a crate structure.

The intermediate crate which resulted from this project is of a design which more effectively incorporates the sheathing of the crate into the structural design. The result of this design is a 33 percent reduction in the lumber required for some sizes of crates and a minimum reduction of not less than 10 percent. The design resulted from analysis of current specifications for crates which indicated that the sheathing usually served no function in the structural design. The fallacy on sheathing has been that its function was only considered as serving to provide a protective shield or screen for the items contained in the crate. Analysis of the actual functions of sheathing indicates the following: Sheathing provides means for positioning and interlocking the frame members; serves as gusset plates at junctions of frame members; serves as the only tension members of the sides when the crate is lifted by grabhooks. In most instances, the compression strength of the sheathing exceeds that of the frame members and by using this compression strength in the structural design the size and number of frame members can be reduced. Also, the proper use of horizontal joist supports distributes the load of the top to the sides and allows increased space between roof joists. The double sheathed top design also allows for greater spacing of the top joists and saves material. The crate base construction is lighter because the use of sheathing as a structural portion

of the crate reduces the deflection of the base which is the cause of most base failures. Crate bases of previous crate designs were constructed to support the load during handling prior to complete fabrication of the crate.

A less substantial base can be used if no handling is involved prior to complete fabrication of the crate. This can be seen in the fact that the entire side panel and outer skid are then a portion of the supporting beam. The section of the beam becomes quite large and the deflection is negligible; however, as the length of the container increases, the nailing or fastenings of the sheathing to the base are placed under increasing shear stress. At increased length two types of fastening failures occur, one is bending or pulling the fasteners out of the skid and the second is separation of the wood fibers of the skids by the fasteners. A large lumber saving can be made in the base if the procuring agencies will determine whether or not the 2-inch flooring in the fork-lift truck finger areas is necessary. The heavy flooring is not required when uniform loads exist in these areas. The draft of the specification is now in process of coordination prior to publication.

Specification JAN-P-104 covering Nailed Wood Sheathed Crates is also in process of revision. Changes as proposed by other Services and by the Forest Products Laboratory provide for a reduction in roof load capacity from 175 pounds per square foot of roof area to 100 pounds per square foot with a resultant reduction in the size and spacing of some frame members. Provision is also being made for fabrication of this type of crate as a demountable container for reuse. Where such reuse is practicable, a considerable saving in lumber should result.

The use of open crates with or without liners can provide an acceptable container in many instances and also produce large economies in lumber consumption.

Specification JAN–P–132 for open crates up to 2,500 pounds capacity is currently under study for increase in its range of usefulness in addition to the provision of more specific design details.

Drafts of a new specification for open crates of larger capacity are in process of acceptance by the Military Establishment. This includes design requirements developed by the Forest Products Laboratory providing for contents of weights in excess of 2,500 pounds which is the top limit for Specification JAN–P–132 crates. Provision is made for two designs in separate weight ranges and for both nailed or demountable construction. The crate of lower capacity, 2,500 to 10,000 pounds, is a variation of the standard crate design in Specification JAN–P–104. The design merely removes those portions of the sheathing which are not used to interlock frame members and adds plywood gussets at several other weak points. The crate design for larger capacity, 2,500 to 30,000 pounds, is a radical change in design from any previous military crate. The side panels are formed by horizontal members and two sets of diagonals. The diagonals are placed on either side of the horizontal frame members and in opposite directions, forming a strong structure capable of carrying the required superimposed load. The base is substantially constructed; however, floor members are replaced with diagonals when possible. The top and ends are double diagonal or "X" panels framed on 4 by 4 timbers.

The design has many good features as it has made it possible to use open crates on heavy items of equipment which were not so provided before.

Wood Substitutes in Crate and Box Construction

The Corps of Engineers is actively engaged in the search for substantial wood substitutes to be used in container designs. The Engineer Research and Development Laboratories at Fort Belvoir, Virginia, are currently evaluating and testing several such materials. Each of the materials have certain good properties, but, few of the materials have the complete properties of lumber. Some materials have been combined with lumber to provide suitable shipping containers, others can be used alone if strict control is applied to their use.

Incorporation of wood substitutes for lumber sheathing of crates will force certain new structural designs in the crates. Minor substitutions can be made on present crate designs, such as replacing the top layer of sheathing on a double sheathed top and the end panel sheathing, without causing structural weaknesses. Boxes constructed of combinations of substitute materials with battens, wooden ends and strapping have proven acceptable through performance tests. Current plywood box specifications permit the use of substitute materials for panels with strict limitations as to the quality and thickness of the material.

The use of wood substitutes for lumber in constructing boxes will produce a greater saving in lumber than if they were used on crates. Boxes comprise the largest portion of the shipping containers and are the least economical from the standpoint of conservation of lumber and are inefficient in that they require more footage for a given amount of cubage than do crates. Containers which can be carried by an individual man are a most common size, with weight limitations of 70 pounds or less. Boxes for loads of this weight can be constructed of substitute materials and still meet the performance requirements for overseas shipping containers. The material used in boxes has no useful purpose other than fuel upon use of its contents; however, this is not true of crates.

Salvage of Crate Material

The usefulness of crates does not end when the contents are removed. Combat construction battalions have used the larger containers for construction purposes. The heavy bases have been used for bridges, shoring of damaged bridge structures, and shelters.

During World War II requests were made that more heavy timbers be used in large crate buses so that they would be available in front line areas. The reasoning was quite sound because the space required for a crate was not increased by attaching more skids, shipping space was at a premium and lumber storage was concentrated too far from the combat areas for use; therefore, this means of supply was very logical.

It is felt that the measures outlined above, all of which are in a near state of accomplishment, constitute definite progress towards maximum effective use of the available lumber supply and possibilities of considerable conservation of this supply to make it available for other uses than as containers.

Discussion

Kauko Kuoppa–Maki (ERDL, Fort Belvair, Virginia): Speaking of handling, what effect do the new methods of handling have on conservation of lumber in crate design?

Mr. Sargeant: Handling has a great deal of effect as crate design must be such as to meet the worst conditions anticipated. If one could be assured that all crates would be lifted by two properly placed slings under skids and that spreader bars would be used; or that no box-hooks would be used; or that slings would not be placed around sides and ends, as recently was encountered, instead of under the bottom; without doubt a considerable saving in lumber could be effected in crate design.

Earl R. Stivers (Stapling Machines Company): What steps are you taking to assure the proper use of containers—such as correct packing and closing?

Mr. Sargeant: It is the responsibility of the procurement office to carry out the intent of the specifications.

E. George Stern (Virginia Polytechnic Institute): Has consideration been given to the use of special nails in smaller sizes in the manufacture of boxes and crates?

Mr. Sargeant: This question is not being considered by the military at the present time. Some work along this line has been done by the Forest Products Laboratory.

Mr. Stern: What work has been done in revising specifications for containers in light of the availability of the improved threaded-shank nails?

Mr. Sargeant: Since the holding power of these nails is so much greater than that of plain-shank nails, smaller-size threaded-shank nails might be employed which in turn, would allow use of thinner lumber and result in saving of lumber. Reference is made to the Paper (No. 180) on "Nails and Screws in Wood Assembly and Construction," which contains basic information on the comparative holding power of plain-shank and threaded-shank nails and wood screws.

Armin Elmendorf (Elmendorf Research Inc.): Crates weighing less than 500 pounds should protect the contents and also provide holding area. What are the relative merits of the braced frame crate, with the contents covered, versus the plywood sheathed crate.

Mr. Sargeant: This naturally depends on the nature of the equipment. For equipment which does not require high protection from moisture, an open crate can provide adequate protection from mechanical damage and facilitate handling, stowage and storage. If protection against water and pilferage is essential, a fully sheathed crate should be used. In the interest of lumber conservation however, the military services are giving increased attention to possible greater use of open crates, and also of partial housings over critical parts of equipment in lieu of crates.

J. R. Watkins (Watkins Patents, Inc.): You made no mention of specification JAN–P–108 for fibreboard boxes. Is a revision of this specification being considered?

Mr. Sargeant: Revision of specification JAN–P–108, which covers fibreboard boxes of either V or W board, is not in the program at this time as it is considered to be satisfactory both for interior and exterior containers. It is thought that greater use should be made of proper type fibreboard containers in lieu of wood boxes where type of load permits.

R. C. Fraunberger (Philco Corporation): You mention training the inspection personnel in the intelligent use of the specifications. Do you have a definite action program to accomplish this? Conservation of lumber should be two-fold; size and quality. What is being done to accomplish this?

Mr. Sargeant: It is recognized that inspectors sometimes tend to be somewhat arbitrary and accept only the best material. Training schools for inspectors are now underway at Toledo, Ohio (Army Ordnance) and at Granite, Illinois (Army Engineers).

Military Requirements for Wood in Packaging

CLINTON K. ROYCE, *Head, Packaging Section, Office of Naval Material, Department of Navy, Washington, D. C.*

Introduction

IN DISCUSSING wood requirements of the Packaging Program of the Department of Defense, we are concerned primarily with qualitative rather than quantitative requirements. Quantity-wise it appears that our needs in any future conflict will be at least ⅓ more than our World War II consumption which in 1944–45 was running well over 30 billion board feet annually. In fact, it has been authoritatively stated that on August 14, 1945, half of our total timber harvest was going into containers and packaging materials. Not all of this timber harvest, however, went into wood containers, since paper, paperboard and fibreboard accounted for a substantial part of the total cutting. Boxes and crates used 44 percent of the lumber consumption in 1944 and 37 percent in 1945.

I believe we are all pretty well agreed we have fought our last war in an economy of plenty—from here on we will operate in one of scarcity. Obviously, because our requirements for lumber during World War II reached a point where they could not be met (1944 consumption was 34⅓ billion board feet against production of a shade less than 33 billion and 1945 consumption was 31½ billion board feet while production hit just over 28 billion); we have determined that we must produce more containers per tree than we have ever produced before.

To accomplish this, we in military packaging are doing a great many interesting things.

Standard Groupings Used

To begin with, our specifications for wood containers do not call for a particular grade of lumber, but rather specify species according to more or less standard groupings which have been developed by the U. S. Forest Products Laboratory. These groupings are:

GROUP I

Aspen (popple)	Magnolia
Basswood	Pine, jack
Buckeye	Pine, lodgepole
Butternut	Pine, ponderosa (Western yellow)
Cedar	Pine, red (Norway)
Chestnut	Pine, sugar
Cottonwood	Pine, white
Cucumbertree	Poplar, yellow
Cypress (baldcypress)	Redwood
Fir, Balsam	Spruce
Fir, noble	Willow
Fir, white	

GROUP II

Fir, Douglas	Pine, southern yellow (including pine, North Carolina)
Hemlock	
Larch (tamarack)	

GROUP III

Ash, black	Maple, soft
Ash, pumpkin	Sweetgum (red gum)
Blackgum	Sycamore
Elm, white	Tupelo, water

GROUP IV

Ash, white	Hickory
Beech	Maple, hard
Birch	Oak
Elm, rock	Pecan
Hackberry	

and the specifications say "When any group is specified, any species in that group may be used at the option of the contractor." The groupings have been made on the basis of density, relative hardness and strength and nailing characteristics.

Moisture Content and Other Requirements

Our requirements moisture-wise are more or less standard—that is to say lumber must be seasoned to a moisture content of not less than 12 percent nor more than 18 percent of its oven dry weight. In veneer for wirebound boxes we require that the top limit be held to 15 percent and the low limit is allowed to go down to nine percent.

We have rather rigid requirements as regards knots—their size, frequency and proximity to ends of members. A lot of people seem to think that any kind of lumber can be used in boxes and crates. Experience has taught us otherwise.

I mentioned the fact that we were doing some interesting things about the use of wood in packaging. We are, in fact, in the process of reviewing all of our qualitative requirements for lumber in our container specifications. We are doing this in an attempt to bring about a greater degree of uniformity, to produce better containers and above all else—*to enable us to obtain more containers per tree.*

Field Test

To give you some idea of the extent to which we have carried on this study, it will be appropriate to tell you briefly of one field test recently completed. One thousand four hundred wood containers; that is nailed, cleated plywood and two different types of wirebounds, were packed with typical items which were representative of each load type and weight range currently covered in the three basic container specifications. We found that 100 loadings were required to cover the weight and load-type ranges. It was deemed desirable to compare certain specially designed containers against so-called "depot packs" so we added an engineered pack in each weight class and load type (By types of load, I refer to the military designations of Type I—Easy: Type II—Average: and Type III—Difficult). So we had 200 loadings.

Then, in order to assure an adequate number of containers on which to base an evaluation, it was agreed to place under test seven identical sets of containers or 1400 boxes in all.

A shipment comprised of these 1400 boxes was made from Army Ordnance's Letterkenny Arsenal at Chambersburg, Pennsylvania to 8th Army Headquarters at Tokyo, Japan. An experienced technician accompanied the shipment as an observer and on arrival in Tokyo an evaluation was made. The shipment then moved to the Naval Supply Depot at Subic Bay in the Philippines where, after a second evaluation, it was placed in outdoor uncovered storage for a prolonged period during the rainy season. Following a third evaluation at the end of the storage period, the shipment was returned to the United States, and is undergoing a very complete evaluation at the Food and Container Institute for the Armed Forces at Chicago. I'm sorry I can't tell you of some of the things which will come out of this test. The data which are available are all under classification. A second reason is the fact that much of the data is only preliminary and must be correlated with laboratory data before true evaluations can be made. But of this you can be certain—*much good will come from this test* and our knowledge of performance of shipping containers has been vastly broadened.

When the Army services and Navy bureaus developed a specification in 1945 for sheathed crates, that specification contained the following minimum thickness requirements for sheathing:

Wood Group	Minimum thickness
Lumber:	
I	3/4 in.
II and III	11/16 in.
IV	5/8 in.

Since that specification was written, one of our larger manufacturers of vehicles and farm implements has been experimenting to considerable extent with 5/8-inch sheathing lumber which is resawn from 6/4 stock and finished on one side. This firm claims a saving of 20 percent of the tree with this operation and of course we of the military establishment are very much interested. We have the matter under study right now.

During the latter part of the last war, one of the large producers of wood containers began to produce cleated and wirebound boxes made with panels of thin veneer to the faces of which had been laminated sheets of fourdrinier kraft paper. This material which represents a substantial saving in natural resources is another which is currently under study by the military. In fact one of the large producers of plywood has, since the development of this material, produced in substantial commercial quantities a similar panel board for boxes consisting of veneer core and facings of cylinder kraft paper. This manufacturer has also produced a completely verminproof panel by impregnating the kraft facings or liners with asphalt.

The services have experimented successfully with and there is a specification to cover a fibreboard lined wood box which makes use of very thin wood members. These containers which combine high strength factors with light weight as do those made from the kraft laminated veneer core panel stock, have a tremendous potentiality in the movement of general cargo by air. Here, savings in tare weight are an important factor, yet strength of the container cannot be sacrificed for material moving by air for the military usually has a ground handling at each end of the air trip and in wartime, one of these ground handlings is inclined to be a bit rough.

Discussion

Dr. Frank B. Smith (Dow Chemical Co.): In view of the anticipated shortage of lumber for packaging, is it fair to ask what the military is doing in the treatment of lumber with preservatives to increase its service life?

Mr. Royce: This is recognized as an acute problem. There is a requirement covering the use of preservatives in container-grade plywood. This is a carryover from the time when preservatives were required to protect the glue line. This requirement should be extended to nailed and wirebound boxes. In an overseas test 20 percent of the boxes were preservative-treated and showed a marked improvement in durability. A great deal of thought is being given to incorporating preservative treatment requirements in all packaging specifications.

R. C. Fraunberger (Philco Corporation): Please elaborate on the 20 percent saving mentioned on resawing 6/4 stock to 5/8? Is this 5/4 a misprint in the paper?

Mr. Royce: The 20 percent saving represents a combination of the $\frac{11}{16}$ and 4/4 dimensions previously used.

J. R. Watkins (Watkins Patents, Inc.): It has been noted that container manufacturers are not, in general, familiar with JAN specifications for containers, nor are they familiar with Forest Products Laboratory packaging research work. Information is desired as to whom to contact in the military to discuss a new packaging method that will save substantial quantities of wood.

Mr. Royce: Contact should be made with the Munitions Packaging Board or Staff Officers of the Departments of the Army, Navy or Air Force in Washington, D. C.

Mr. Watkins: Is steel strapping as good as it is claimed to be?

Mr. Royce: If properly used, steel strapping is a tremendous additive to the strength and durability of the containers, particularly in the case of light containers. Because of shrinkage, it is inadvisable to strap wet lumber without provision for retensioning. The size, location and number of straps are important and frequently highly controversial.

Wood Requirements for Specialized Military Uses

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This paper sets forth some of the activities normally carried on by the Quartermaster Corps as well as to point out requirements for substitute wood and wood products due to the unavailability of properly seasoned woods and veneers in time of an emergency.

Introduction

THE Quartermaster Corps is a service organization to the Department of Defense and holds responsibility for the development of the individual soldier's clothing and equipment, foods, fuels, and lubricants as well as the performance of other services and functions. The Research and Development Branch is charged with the responsibility for preparation of specifications on which procurement of these items is to be made. Efficient specifications are a basic requirement for the satisfactory purchase of commodities in our industrial economy. Back of all specifications must first be the accumulation of practical and technical information on which they are to be based, and in supplying such information research plays an important role in the field of forest products. It is self-evident also that specifications and methods must be practical and to this end various considerations and research findings must be tempered by judgment and experience in their application. In many cases it has been possible in the revision of specifications to facilitate and expedite procurement by broadening the species base or modifying restrictive requirements without affecting the quality or serviceability of the product.

The Research and Development Branch is separated into Sections concerned with the responsibility for chemical and plastic items, textiles, clothing, footwear and mechanical items. It is within the last named Section of Research and Development Branch, the Mechanical Section, that responsibility is held for the development of wood items used by the individual soldier. Besides numerous military items the Quartermaster Corp is charged with the responsibility for furnishing thousands of items in the housekeeping category. The problem of preparing specifications on which the solicitation of bids is to be made on large scale procurements is a tremendous task. It is difficult to design the many types of various items so as to permit commercial manufacturers to produce these specialized items, at maintained quality levels, and not interfere materially with normal production. These specifications must set up minimum acceptable standards in order to permit an equitable evaluation of bids. The designer of the equipment, therefore, selects the materials as to availability, economical, and practical characteristics. In an emergency, however, when all materials are scarce, he is immediately plagued with the incorporation of substitute materials, and the engineering problem is sometimes placed in a complete redesign stage. In order to provide the contractors with assistance in obtaining critical and scarce materials, the Industrial Mobilization Office has been set up for the purpose. Phases which affect the designing of military equipment materially are factors for the provision of (1) portability (2) rapid repair and (3) interchangeability of parts. For portability and rapid manipulation the design of wood products usually relies upon fasteners, connectors and other similar metal components on which the success of the item in field use is dependent. Usually the field equipment furnished the soldier, must of necessity, due to excessive handling, shipping and storing, be constructed much more durably than for its single function as an end item. Since the Quartermaster Corps is charged with the housekeeping functions, it is likewise charged with the responsibility for repair and upkeep of the items during their service life. This requirement imposes upon the designer of military equipment the additional hardship of obtaining interchangeability of parts between items manufactured by various producers. Hence closer tolerances than normally required must be insisted upon.

During World War II the largest single item was that of lumber for shipping containers so essential for the protection of various war products during transport to all theaters of operation and during storage. For this use alone about one-half of the 34 billion board feet annual output of lumber was allocated. Demand for special paper and paperboard for packaging to withstand severe conditions and for various uses as substitute for more expensive or more scarce materials in addition to the essential ordinary uses were enormous.

Furniture Requirements

The wood requirements for specialized military uses concerning the Quartermaster Corps might well be separated into three categories, (1) furniture

items (2) field equipment items and (3) oversnow equipment items. The Army is the largest single buyer of furniture in the world. During the period from 1946 to 1950, upward of 45 million dollars were expended for furniture for officers and non-commissioned officers quarters. Approximately the same amount of money was expended for office furniture and items of office equipment. The items of office equipment are procured on specifications alined with commercial production, the principle wood being red oak. The furniture for officers and non-commissioned officers quarters is classed as military equipment in view of the problem of maintaining interchangeability and supply of repair parts in the field during the life expectancy period of 20 years service. Two types of quarters furniture have been developed for specific military uses. Wood furniture of conventional construction is used in posts, camps and stations throughout the United States and a combination construction of metal-wood is used for Army stations overseas. The furniture of all wood construction is of Classic 18th century design. The face veneers are either walnut or mahogany. The solid wood components are constructed of beech, birch, sweet gum, hickory, mahogany, walnut, hard maple or pecan. The selection of these hard woods permit manufacturers in either the southern states or the northern states to utilize lumber grown in their particular locale. The most critical problem during the procurement of this furniture was obtaining good grade poplar for the lumber-core panels. The unavailability of chestnut for this use has imposed a hardship in obtaining a suitable lumber-core material and has placed such a drain on poplar wood that shortages have been felt throughout the country. Substitute woods are permitted such as white ash, aspen and basswood, butternut, magnolia and red alder to alleviate this condition. Development by the Forest Products Laboratory has established the fact that vertical grain redwood lumber is a suitable substitute for use in lumber-core panels and as a result of this development a new source of supply will be available to furniture manufacturers. The combination metal-wood type of furniture eliminates the requirement for solid wood components inasmuch as the panels themselves are mechanically secured to a metal framework. In this way the use of glues susceptible to mold and fungus deterioration are eliminated.

Miscellaneous Field Equipment

The Quartermaster Corps procures large quantities of miscellaneous field equipment items utilizing wood and veneers such as plywood packboards, tent pins and poles, handles for striking tools, canvas folding cots, shelter frames and flooring, field desks and locker boxes. The plywood packboard is preformed from hardwood veneers of beech, birch, hickory or maple. This procedure requires a great deal of production time for the molding of this item in heated dies. If post-forming could be accomplished in the forming of a 90-degree bend on each side of the packboard tremendous savings of production time could be made. Considerable amounts of wood pins and poles are purchased, giving employment to smaller mills and groups of manufacturers with simple equipment. These items utilize lower grades of non-critical wood. Striking tool handles, however, require a high-grade hickory. Considerable difficulty has been encountered with wood items when subjected to extreme cold temperatures. The low temperatures and low vapor pressures tend to draw the moisture out of the wood making the component item very brittle and susceptible to splintering and breaking. Research in this field is definitely needed in order to bring about a satisfactory solution to the problem. Plastic coatings or impregnations which will retard or prevent the escape of moisture may aid in this development. The canvas folding cot utilizes ash, beech, birch, maple, rock elm, hickory, red or white oak and pecan.

Field Desks and Locker Boxes utilize 3/8-inch 3-ply veneer. Douglas fir exterior grade BB or Hardwood Type I and II grade 2, conforming to the requirements of military specification MIL-P-66 are specified for these items. A great number of the field desks and cases are covered on both sides with vulcanized trunk fibre to give increased wear and durability. Plywood as you know is a scarce material in time of an emergency. In order to alleviate critical shortages, substitutes for plywood are under constant surveillance. The plywood panel or the substitute panel or both when developed would have to permit the driving of bifurcated rivets by machines, without splitting or tearing out of the grain structure. The BB exterior grade Douglas fir plywood is difficult to obtain due to the fact that large production of plywood for the building trade is AD grade. The AD combination requires a clear, matched, sound face and a back permitting open defects. In the development of the Army field cases, however, it is required that the plywood be not matched for grain and color, but only that it be sound on both sides. It is obvious that when an AC plywood is used the A face covered with vulcanized fibre covers up the face that was matched for color and grain thus obviating an unnecessary expense and requires the covering of the C face with open defects that could later cause depression and indentation through the vulcanized fibre facing. Large scale production of plywood with sound faces and backs or a suitable substitute panel is greatly needed.

Over-Snow Equipment

Some of the over-snow equipment items are skis, sleds, snowshoes and toboggans. Of these items the skis are the most difficult articles to manufacture. The Army ski is made of laminated construction to utilize lower grade wood and resist twisting and warping. The two greatest manufacturing problems are the obtaining of good grade hickory and main-

taining uniformity of skis between various manufacturers. The manufacturers of skis in the past, experienced considerable difficulty in procuring a sufficient quantity of the choice hickory to meet Army demands. Several manufacturers stated that large quantities of choice hickory are being shipped to several of the European nations and in several instances it has been necessary for manufacturers in the United States to buy hickories back from these same European nations. The result is that they must pay an enormous premium for this wood.

The construction of the ski is so designed as to produce a three-layer ski. The top layer and bottom layer require the use of true hickories and may be fabricated from five to seven pieces of edge-glued material. The center core of the ski utilizes lower grade wood such as pecan, hickory, white ash, yellow birch, and sugar maple. Skis are procured in quantities and every ski must follow a set curve when pressure is applied at a given point. No soft spots or stiff flat portions are permitted when the ski is depressed. The ski must follow a smooth continuous curve, otherwise it is rejected. The specifications suggest that the contractor use the drying schedule as published by the Forest Products Laboratory for seasoning the hardwoods. For the production of snowshoes a clear white ash is required for the wood bows and cross bars.

Discussion

Kauko Kuoppa–Maki (ERDL, Fort Belvoir, Virginia): Regarding shortage of hickory. Couldn't substitutes be accepted? About 80 percent of skis in military use now are faced with birch on the bottom.

Mr. Paden: Other materials are being used. Currently there is an ample supply of maple, which is considered superior to birch as an alternate material.

George W. Trayer (Forest Service, U. S. Department of Agriculture): You didn't mention shoe last blocks. Are there any problems in this regard?

Mr. Paden: There is a problem in the supplying of rock maple in sizes adequate from which to turn solid shoe lasts.

Mr. Trayer: What is the supply problem regarding specialty woods?

Mr. Paden: The supply problem of specialty woods for shoe lasts to meet military requirements has brought out the fact that there is an inadequate supply to satisfy abnormal requirements. Experiments are being carried on with laminated shoe last blocks, and it appears that this type of construction will give assistance in the supply of wood for shoe last blocks.

George M. Hunt (Forest Products Laboratory): Mr. Paden's paper indicates that wood becomes weaker when very cold. All the evidence I have seen indicates that wood becomes stronger as it gets colder. I wonder if there is technical evidence in support of Mr. Paden's statement to the contrary.

Mr. Paden: This is believed to be related to the molecular structure of wood.

E. George Stern (Virginia Polytechnic Institute): In response to Mr. Hunt's discussion, I wonder whether his statement that wood increases in strength when frozen is limited to static loading conditions? Confirming data for static loading were published recently by F. Kollmann in his paper on "Investigations on Reasons for Degrading of Green Oak During Seasoning and on Strength Properties of Wood in High-Frequency Field (In German)," Sven. Traforskningsinst. Tratekn. Avdel., Medd. 21, 1950.

Charles H. Jeter (A. J. Hodges Industries): I am surprised that there is a shortage of hickory. In the South we are spending money to destroy it.

Mr. Paden: Ski manufacturers would welcome a good source of supply.

Mr. Trayer: There is no shortage of hickory timber in general. However, there was a shortage of high-quality, tough hickory for picker sticks, shunt poles (a lend-lease item), ladder rungs, and handle and ski blanks during World War II. The supply of hickory for these and perhaps other items is likely to again become limited by specifications as to quality and size.

Mr. X: Is the one-piece ski considered practicable for Army use?

Mr. Paden: The military ski has been constructed on the 3-ply principle for the purpose of utilizing lower grade woods and insuring the production of a ski resistant to twisting and warping. Each of the 3 layers is composed of 3 to 5 pieces of wood. The outer plies are of true hickory, but the inner plies utilize white ash, yellow birch, sugar maple and pecan.

The one-piece ski is not considered practicable for Army use because of the fact that it requires a top grade of material for the entire ski and does not offer insurance against twisting and warping in field use and long term storage.

Mr. X: Would you please describe a little more in detail, the construction of the metal-wood furniture you mentioned?

Mr. Paden: The metal-wood furniture designed for military use overseas is designed to resist high heat and humidity and requires the minimum of maintenance throughout its service life. The frame work employs metal to which flat panels can be secured mechanically, permitting rapid repair by non-skilled personnel. This employs metal to the best advantage to resist twisting and warping and employs lumber for plywood panels on the exterior of the piece of furniture in order to gain the warmth and beauty of the wood.

The frame work is constructed of either aluminum or steel U-shaped channels approximately $1\frac{1}{8}$ inch square. The lumber core panels $\frac{3}{4}$ inch thick are secured to the frame work with sheet metal screws. The frame work is welded or riveted.

Place of Small Business in the Military Procurement Program

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Introduction

HARDLY ten years have elapsed since World War II required us to marshal the industrial resources of the United States in men, machines, materials, capital and know-how in support of our military forces. Marshalling these resources produced a long list of dislocations and well toward the head of the list stood small business. Between the limitations placed on the use of strategic materials for civilian goods and the awarding of a majority of the defense dollars to larger corporations, thousands of small businesses were on the verge of closing their doors. The plight of small business received much attention and a great deal of effort was expended in an attempt to establish a place for small business in service procurement. With the surrender of Japan in 1945 materials again became available to small business and its interest in participating in service procurement terminated.

Whatever respite small business had from the problems of World War II was short lived. The armed conflict in Korea turned back the hands of the clock and a familiar pattern began to repeat itself. Again limitations have been placed on the use of strategic materials for civilian products. The awarding of a majority of the defense dollars to larger corporations is following the pattern of World War II. There is, however, an important difference between the mobilization efforts for World War II and the Korean conflict. The former was a total mobilization, while the latter is only partial.

With small business again facing the problems of World War II, a place for small business in service procurement is being sought. The search is controlled today, however, by a set of circumstances which are readily distinguishable from those existing at the outset of World War II. At that time we were emerging from a prolonged depression whereas the Korean conflict arrived as we were nearing a record-breaking national income of 223.5 billion dollars in 1948. The mobilization effort starting in 1941 was a total effort, reaching its peak in 1944 with expenditures approaching an annual rate of more than $90,000,000,000. The mobilization effort beginning in 1950 is partial and will reach an approximate annual rate of $50,000,000,000 by the end of fiscal 1951. The World War II mobilization was an all-out effort to achieve victory and end the war. The duration of the small business problem could be considered limited by the length of time required to accomplish this objective. Today, the end of the fighting in Korea does not necessarily herald the end of limitations on the use of materials and the resultant need of small business to participate in service procurement. The foreseeable duration of World War II was certainly a controlling factor in the choice of a solution to the problem. The need for the development and implementation of permanent plans are clearly indicated today since the duration of limitations on the use of materials and the duration of partial mobilization is unpredictable.

Trade Regulations

Basically, the need of small business for a place in service procurement is a function of a trade regulation which limits the free use of materials and restraints in trade, decreasing competition through the placing of a majority of defense dollars with a limited number of corporations. Since the problem may be with us for some time to come, it seems desirable to examine it briefly in the light of the historical background of trade regulations and restraints in trade.

For centuries, trade in England was closely regulated by government and it was the custom for government to sponsor and protect monopolies, as for example the Medieval fairs and markets which were monopolies granted by the crown. In the 16th Century, the fair and market monopolistic domination of trade passed to the towns with the guild merchants performing the task of protecting and regulating trade. The function of the guild was to preserve to its members the monopoly of trade and regulate the trade of the town in general. Gradually, the guild merchants were replaced by craft guilds formed primarily to regulate and preserve the monopoly of each trade within the town. They usually existed under the authority of the town government and membership was achieved by passing through various stages of apprenticeship, journeyman and master. The craft guilds gradually lost control of the regulation of trade and popular opposition to the granting of monopolies forced the

crown to concede in 1601 that the validity of a monopoly would be tried at common law. In 1623 the English statute of monopolies was passed and monopolies were declared void and thereafter to be determined and tried at common law.

Over this medieval industrial era was draped an all-encompassing code of state regulations of production and distribution. About the middle of the 18th Century the system began to disintegrate under the impact of the industrial revolution and the regulation of economic society by the state which had been traditional policy was discredited. The continuance or extension of the supervision of government over labor, wages, hours, industry, commerce, agriculture or production, distribution and exchange was opposed. This, the laissez-faire theory of the functions of government, reached the peak of its popularity about 1830.

In America, the colonists conformed to the views on trade regulations prevailing in England. Prices and wages were frequently fixed by ordinance and monopolies had their counterparts in the colonies. After the revolution industrial expansion was rapid and the period from 1860 to 1890 was one of unrestricted factory development. Population nearly doubled and invested capital rose from a little over 2 billion to 6½ billion. It was an era of corruption, exploitation and rapid national growth. With laissez-faire the philosophy of the day and government conspicuous by its absence from the field of trade regulations, abuses growing out of the expansion of the railroads and the predatory trade practices of the Standard Oil trust and others, resulted in the injection of government back into the regulation of trade. Over a period of years a series of legislative acts were passed aimed at preventing monopoly and maintaining competition. The Sherman Anti-Trust Act, passed in 1890, was aimed at combinations or conspiracies in restraint of trade and monopolies. The Clayton Act, in 1914, stipulated that no corporation might acquire stock in another corporation where the effect of such acquisition was to lessen competition or create a monopoly, nor maintain common directors between two corporations where either one had capital surplus or undivided profits in excess of $1,000,000, so that the elimination of competition by agreement would violate the anti-trust laws. The Federal Trade Commission Act in 1914 authorized the Commission to prevent unfair methods of competition in commerce. The Robinson–Patman Act in 1936 made it unlawful to discriminate in price between two or more purchasers. In addition many regulations were passed by the individual states.

The transition has been therefore from the state-created and controlled monopolies; to the voiding of monopolies by statute; the retreat of government from the regulation of trade; and finally, the return of government to the area of trade regulations charged with the maintenance of competition and the prevention of monopolies and restraints in trade. The return of government to the regulation of trade served notice that the destruction of a segment of American industry through unfair competition and the growth of monopolies was inimical to the national welfare. Small business, the segment of industry most susceptible to this form of attack, was thus recognized as vitally important to a healthy industrial growth.

We have seen that World War II limitations on the use of materials and the placing of prime contracts with the larger corporations constituted a trade regulation and a restraint of trade unless small business was aided in overcoming a competitive disadvantage. Small business found it difficult to find out what was being purchased and procurement officers were ignorant of his existence. The procurements he did learn of were apt to be beyond the scope of his facilities, financial capacity or ability. Having suffered through the first two years of the war, small business made itself heard, and, Congress passed the Smaller War Plants Corporation Act. The Act was passed in June of 1942 but the corporation did not function too effectively according to reports until 1944. SWPC actively engaged in assisting small business to acquire prime contracts and to a lesser extent subcontracts. It was empowered to make direct loans for plant and equipment, to supply working capital and to lease equipment to small business. The participation of small business during the days of the SWPC is pointed out as significant of the need for such legislation. It cannot be overlooked, however, that as SWPC swung into action an all-out search was on for additional productive facilities. The participation of small business might very well have been achieved without this instrumentality.

With the end of World War II, the country embarked on an era of unprecedented prosperity. Production reached an all-time high. Big business and small business as well found themselves with all the work they could handle. Military procurement continued on a much smaller scale and generally speaking, industry was disinterested in participating in either current procurement or mobilization planning. In spite of the lack of interest on the part of many industrial organizations, the desirability of being able to mobilize industry quickly in the event of another armed conflict was self-evident to those in military circles. A Production Allocation Program was therefore established. Plants were surveyed and production schedules set up with two objectives. The first objective was the elimination of competition between the services for a given facility, and the second objective was to acquaint the planned source with the item he would be asked to produce, thereby materially cutting down the lead time required to get into production. Designed to cope with a state of total mobilization, implementation of the plan during the present state of partial mobilization has not been an unqualified success.

Qualification is the Test

What then is the place of small business in the service procurement program? The ultra conservative among procurement personnel contend that the primary mission of service procurement is to get the equipment with consideration only for quality, time of delivery and price. The proponents of the opposite extreme, advocate turning service procurement into a public works program. It has been contended in some quarters that the natural role of small business is subcontracting, leaving prime contracting to the large corporation. The extremes in either case seem entirely unrealistic, leaving us to search out a middle ground reasonably satisfactory to all parties.

There is no apparent logic to employment of size as the determining factor in the classification of a corporation as a prime or subcontractor although such often appears to be the case. Qualification is the logical test and is being employed. Where a business is naturally qualified to be a prime contractor, such business has a place in service procurement as a prime contractor. Where a business is not qualified to perform as a prime contractor, and the majority fall into this category, its place in service procurement must be achieved through subcontracting. The services simply cannot afford to carry unqualified producers on their backs, whether large or small.

If the place of small business in the service procurement program is based on qualification rather than size, what precludes small business from participating, and what is being done about it? A great many qualified small businesses are participating in service procurement but it is not denied that a great many others are not participating and have found it difficult to place themselves in a position to obtain consideration. When an armed conflict is precipitated, monies must be appropriated for military equipment and an all-out effort made to place contracts as quickly as possible. Under these circumstances, the procurement officer turns to the organizations he is familiar with and knows can do the job; either by general reputation or through personal contact during the months and years preceding the emergency period. He knows the quality of the management, the financial condition, the ability to produce, the type of equipment, and the quantity and quality of production that can be expected.

The majority of small businesses qualified to be prime contractors are unknown to the procurement officer since service procurement holds no charm during peace time. However, in the face of an armed conflict, restrictions on the use of materials make it a different story as would-be primes swarm in upon the procurement officers. The job of separating the qualified small business from the unqualified has proven so herculean that it is not surprising to find those who would reject the whole proposition. Obviously, the job of procurement cannot be suspended while the job of separating is done.

A further complication has resulted from the placing of current procurement with sources that cooperated with the Production Allocation Program and accepted production schedules during the days prior to Korea. It has been argued that failure to use planned sources would constitute a breach of faith, making it impossible to enlist the cooperation of industry in any future planning. Further, it is contended that without the program the services would again be competing for facilities and the time to get into production on long lead time items would be increased. The program is under heavy attack, however, since the plan was designed to operate under conditions of total mobilization with defense spending at perhaps twice the present volume. It is argued that implementation of the plan during a period of partial mobilization and restrictions on the use of materials has frozen out a large part of industry. So many complaints have been registered that a restatement of the objectives of the program and a restudy of the items included therein has been deemed advisable by the Munitions Board.

Procurement Information

What has been done to acquaint procurement personnel with qualified small business and to inform small business about the equipments being purchased? Small business liaison officers have been established in all procuring activities to discuss service procurement with business representatives. Each service has published pamphlets to guide small business in its efforts to participate. The Commerce Department publishes daily a synopsis of invitations to bid. A synopsis of unrestricted contract awards over $25,000 is also published by the Commerce Department. Representatives of all three services have toured the country to discuss participation in service procurement with business groups.

While it is conceded that much has been accomplished in terms of supplying information to small business, the critics contend that the supplying of information does not, in and of itself, provide an equal opportunity for small business to participate and, since information cannot replace positive action, falls far short of achieving the intent of Congress that small business shall receive a fair share. However, since the declaration of a state of emergency by the President on December 16, 1950, there has been a marked decrease in advertised procurement and loud criticisms are again being levelled at the amount of procurement information available.

Complaints from small business to members of Congress have prompted the proposal of a number of bills designed to assist small business. These bills have consistently proposed establishing an agency with authority to remove any procurement from the hands of the procurement officer where deemed

advisable and to place the procurement with such small businesses as it may select. Proposals of this sort have been unequivocally opposed by the services on the grounds that proper logistic support for a military force can not be achieved where the performance of such support is taken out of the hands of procurement personnel while leaving them charged with responsibility.

A hornets nest of criticism has resulted even in the area of the Commerce Department's synopsis of invitations to bid, the area calculated to afford a maximum opportunity for small business to participate. The cost of preparing blue prints and specifications precludes stocking an unlimited supply and on occasion the estimate of the requirements has fallen short of the demand. The irritation of those whose requests can not be filled is understandable. Although there have been instances where the investment in drawings and specifications has come close to the cost of the procurement, every effort is being made to satisfy the requests.

Positive Assistance

Realizing the serious consequences that would result if small business failed to participate sufficiently in service procurement, and mindful of the comments of Congress that to date the aids to small business had been, for the most part, informational and not positive action, the Armed Services Procurement Regulations Conference appointed a small business subcommittee made up of members of the three services. This committee was asked to study the small business problem and to prepare and recommend a positive course of action for consideration by the Munitions Board which would form the basis for a permanent solution.

The Small Business Subcommittee, in its report broke down the possible aids to small business into two groups (1) those which were within the authority of the Department of Defense without direction from higher authority or additional legislation and (2) those requiring enactment of legislation. It was the opinion of the subcommittee that a positive course of action could be charted having a good chance to solve the problem without resorting to legislation. Five recommendations were accepted by the ASPR conference and forwarded to the Munitions Board. First, it was recommended that small business specialists and small business target objectives be established within each procuring activity. Small business liaison officers had been in existence for some time but the scope of their activities had been limited to the disseminating of information. It was now proposed that the small business specialists should play a much broader role and perform functions including the following:

(a) Serve as a focal point in the procurement office to which small business concerns may make or direct inquiry concerning participation in the military procurement program and concerning advice or assistance in the performance of military contracts.

(b) Assist Federal, State and authorized private agencies, if requested, in making an inventory of the productive facilities of small business concerns and arrange to furnish those agencies such data concerning small business sources, facilities, and capabilities as the procurement office may have on hand.

(c) Institute a program to discover small business sources capable of participating in procurements to meet current and anticipated requirements.

(d) Review requirements prior to procurement action and determine to his own satisfaction which requirements are susceptible of accomplishment by small business.

(e) Make recommendations to the contracting officer with respect to competency, capacity, and credit of a specific small business concern or concerns capable of accomplishing a specific requirement.

(f) Make appropriate recommendations to the contracting officer in connection with the issuance of certificates of necessity, defense order priorities and allocation ratings, financing, furnishing of government equipment and other measures which will assist them in the conversion and equipping of their plants for the accomplishment of defense production.

(g) Certify to the contracting officer, based on approved criteria or on certification from approved sources, the concerns, firms, persons, corporations, partnerships, cooperatives, or other business enterprises which are to be designated "small business concerns".

(h) Participate in meetings of Boards of Contract Awards or Review Committees where such boards or committees have been or may be established.

(i) Recommend to the contracting officer or such other officer as may be designated by the appointing authority the award of a contract to a specific small business concern for the purpose of broadening the industrial base.

(j) Furnish assistance to small business concerns on problems arising during performance of contracts such as financing, defense order priority and allocation ratings, inspections, and payments, or direct such contractors to the proper agencies for assistance.

(k) Obtain information, where practicable, concerning the methods and terms used by prime contractors in letting subcontracts; and make recommendations to the appointing authority with respect to those practices which discourage small business concerns from taking an interest in subcontracting or which are unfair and inequitable as to price and conditions.

(l) Maintain liaison and exchange information with other local government agencies for the purpose of rendering the maximum amount of assistance to small business.

(m) Review, prior to submission, procurement office reports concerning the letting of contracts and

subcontracts to small business concerns and make pertinent comments to the appointing authority regarding such reports.

(n) Recommend small business target objectives to the appointing authority, with reference to the percentage amount of dollars which should be awarded to small business concerns.

(o) Review small business target objectives, periodically or when directed by the appointing authority for the purpose of recommending revised target objectives.

(p) Observe the effect of current procurement policies on the amount of small business participation in the procurement program and recommend to the appointing authority changes in existing policies or the formulation of new policies to increase the amount of such participation.

Second, it was recommended that Federal, State and community agencies be enlisted to coordinate and facilitate the efforts of small business to participate in service procurement. Third, it was recommended that in appropriate circumstances prime contracts be placed for components parts and an additional prime contract with the assembler of the equipment or purchaser of the components. Fourth, it was recommended that the Armed Services Procurement Regulations be amended to include a statement of Department of Defense policy with respect to negotiated procurement similar to the policy previously included for advertised procurement. Fifth, it was recommended that a notice of negotiation be published prior to the negotiation of certain procurements. The five recommendations of the subcommittee were adopted by the Munitions Board, together with the following statement of the Department of Defense procurement policy regarding assistance to small business and broadening the industrial base of suppliers.

(1) Review of the Production Allocation Program, for the purpose of determining those items which can be procured from a broad number of sources and from various classifications of industry.

(2) Maximum use of available industrial capacity, with limited use of Certificates of Necessity in those cases where necessary industrial capacity is not available.

(3) Review of military requirements and procurement methods, for the purpose of assisting small business and broadening the industrial capacity if not available.

(4) Establishment of a training program for procurement personnel covering the problem of small business and the need for broadening the industrial base of suppliers.

(5) Encouragement of subcontracting, with each important and substantial negotiated purchase to be examined to determine the extent to which subcontracting should be encouraged or required. The extent of subcontracting shall be considered as one of the factors in the negotiation and pricing of prime contracts.

(6) Payment of justifiable price differentials in negotiated procurements to accomplish the objectives of broadening the industrial base of suppliers.

(7) Appointment of small business specialists in procurement offices to increase small business participation in defense procurement.

(8) Adoption of a broad publicity program covering (i) basic objectives of broadening the industrial base of suppliers, (ii) purchase methods and practices, (iii) aids to small business, (iv) the number and dollar amounts of prime contracts awarded to small business, and (v) the desirability and extent of subcontracting.

Concern over the degree of participation of small business in service procurement was manifested in another quarter when General Harrison, DPA Administrator, established the Defense Production Authority Executive Committee for small business. Represented on the committee are the three services, the Munitions Board, NPA, GSA, DPA, AEC, and the GAO. This group is prepared to develop and implement additional policies in behalf of small business.

Summary

Monopoly and restraints in trade are no longer the order of the day but government is again deeply involved in the regulation of trade. The Sherman, Clayton, Federal Trade Commission and Robinson–Patman Acts were passed to maintain competition and free small business from predatory trade practices incompatible with its survival. As in World War II, the substitution of military procurement for civilian buying has forced small business to search for business under unfavorable circumstances of competition tending toward monopolies and the suppression of competition. In World War II a solution was sought through legislation and it is again being suggested. The services have been accused of limiting their assistance to small business to information only but no positive assistance. The services do, however, consider it imperative to render positive assistance to small business in order to eliminate competitive disadvantages and assure the survival of small business. To this end, personnel are being established in all procuring activities, not merely to supply information, but to represent small business at every stage of the procurement action. Every assistance will be given to Federal, State and community organizations in order to make known those small businesses qualified to be prime contractors, and as much procurement information as practicable will continue to be available to small business. The interests of the small business whose role must be that of a subcontractor will not be ignored but accorded equal assistance within its orbit. Small business has a place in service procurement limited only by its qualifications and every effort is being exerted to assist it to achieve that place.

Military Marine Wood Usage—Marine Laminating

JOHN G. KUENZEL,[1] *Senior Materials Engineer, Forest Products Research Division, Bureau of Ships, Navy Department, Washington, D. C.*

Strength and durability required to withstand destructive forces and organisms of the sea differ from requirements necessary to withstand forces encountered on land or in the air. Wood continues to be an important ship building material and a source of supply of choice structural timbers is assured as a result of laminating techniques developed by American ingenuity.

The size and quality requirements of wood shipboard members are being solved by laminating. The technology of wood preservation is challenged to solve the problem of supplying wood resistant to deterioration.

Introduction

MARINE laminating is an exact technical art born of World War II shipbuilding needs for large high quality structural timbers. The Bureau of Ships is traditionally dependent upon lumber and timber of the highest grades available from domestic and foreign forests. Those of us in the Bureau of Ships concerned with specifications and quality control of forest products for marine usage recognize that this tradition has been a heritage from the earliest written records of shipbuilding. The Phoenicians, Romans and later European countries successively exploited the choice Lebanon cedar of Mediterranean forests so completely that today only a small grove of 100 trees remains in the garden of a Lebanese monastery. American forests first rang to the shipbuilder's axe almost 1,000 years ago when Greenland Vikings "Eric the Red" and his son "Leif" harvested a cargo of logs from the North American mainland between Cape Cod and Nova Scotia.

The first cargos shipped to England from the Plymouth and Virginia Colonies included cedar logs from Cape Cod and naval stores from Jamestown. Throughout our early history the American white oak and other choice shipbuilding woods were sought and used by every sea power that explored the Western Hemisphere.

Woods for Shipbuilding

The course of history which has led to United States naval supremacy has in our times left its battle scars on our forests. In 1944 the Navy required 9,000,000 tons of steel; during the same period 3,000,000 tons of wood were required for all types of naval military construction, afloat and ashore. It is becoming increasingly difficult to meet the requirements for shipbuilding timbers from our domestic old growth trees. Despite promising recent developments in structural aluminum and molded plastic boat hulls, wood continues to serve many important shipbuilding needs. Wood is our only naturally renewable structural material. It is significant that the present shipbuilding program gives high priority to wooden vessels of non-metallic, non-magnetic, laminated design.

Sawn timber products used in naval construction are of three types: Utility lumber, structural timber, and special boat and shipbuilding lumber. The first type consists essentially of construction or yard lumber generally stocked in grades of No. 1 Common and Better hardwoods and No. 3 Common and Better softwoods. A wide choice of domestic woods from every lumber producing region are procured under grade-marking rules of the various lumber associations to provide the advantages of a competitive market and broad geographical supply sources. Such lumber serves countless purposes including the fabrication of intricate model ship designs at the David Taylor Model Basin utilizing cherry lumber from Pennsylvania, and white pine from Idaho or California; submarine battery wedges made at Philadelphia Naval Shipyard from New England beech or maple; and laminated small boat members and keel blocks made of Douglas fir, southern pine or white oak at several shipyards. Lower lumber grades are also procured at all shipyards for pallets, boxes, crating and dunnage.

The quality of structural timber and special boat and shipbuilding lumber must conform to certain basic principles of design. These materials for use in stage and scaffold plank, shipdecking, planking and framing timbers must be stocked in the highest grades and largest sizes available and their procurement, therefore, presents the greatest problem from the standpoint of available supply.

The principal woods used by the Navy on the basis of quantity required are Douglas fir, southern pine, "other softwoods," white oak and "other hardwoods," in the order named. Considering shipbuilding needs alone, white oak ranks second in the volume required. "Other softwoods" include cedar (southern white, Port Orford, Alaska, and western red), cypress, hemlock, larch (tamarack), pine (white, sugar, ponderosa, red, and lodgepole), redwood, spruce, (Sitka, Engelmann, and white).

[1] The views expressed by the author are not to be construed as representing those of the Navy Department.

"Other hardwoods" include ash, balsa, basswood, beech, birch, cherry, cottonwood, gum, elm, hickory, ironbark, lignum vitae, mahogany, maple, teak, and yellow poplar. The uses for these woods have been evolved through many years of shipbuilding. Because the timbers of tremendous size cut from old growth trees are not always available in the quantities and grades required from eastern and southern forests, the shipwright's choice for material has shifted to suitable species of large size in the Pacific Northwest, Alaska and tropical America.

White oak, because of its structural superiority and durability is an important component of many types of wood hull Naval vessels, including thirty five designs of patrol, landing, district craft, minesweepers, auxiliary transport, salvage and rescue vessels ranging from 70 to 183 feet in length and over twenty five designs of small wood boats up to 63 feet in length. Steam bent or sawn bolted frames, keels, stems, skegs, shaftlogs, knees, stern posts, and deck beams for many of the 50,000 wooden craft in our two-ocean Navy of World War II utilized white oak.

The total white oak requirements for the present wood shipbuilding program are tentatively estimated at approximately 30,000,000 board feet. This is equivalent to approximately one-sixth of the 1950 production of this species in grades of No. 1 Common and Better. The ships will be several years in building, and provisions are made for utilizing treated red oak and other suitable alternate species. As a part of this program, the facilities of American forest products industries to produce laminated ship timbers are being studied for mobilization.

Marine Laminating

The development of marine laminates such as are specified in the present naval wood minesweeper program originated about 1939 or 1940. The process evolved for gluing large straight or curved ship timbers for the Bureau's gigantic needs utilized principles of laminated arch construction introduced in the United States from European sources, with one major distinction. The casein, and urea-formaldehyde glues found to be suitable for interior laminates in shore built structures delaminated in salt water. Modern phenolic resin glues such as have been used in marine or exterior type plywood since 1920 and cured in hot plate presses at temperatures of 350° F. were considered uneconomical in the production of large timbers. The Bureau explored the possibility of high-frequency curing of the high-temperature setting phenolic adhesives about 1941, but preliminary experiments were not promising, due to the variable dielectric properties encountered in large wood assemblies of the species and shapes required for ship timbers.

In 1942, when the need was great the Bureau called a conference of synthetic adhesive manufacturers, presented the problem, and within 6 weeks their laboratories produced, with the help of a Divine Providence and American ingenuity, a resin adhesive curing at a lower temperature than the boiling point of water, and durable under extreme service exposure at sea. A great variety of laminated ship and boat parts have been produced for the Bureau (Fig. 1).

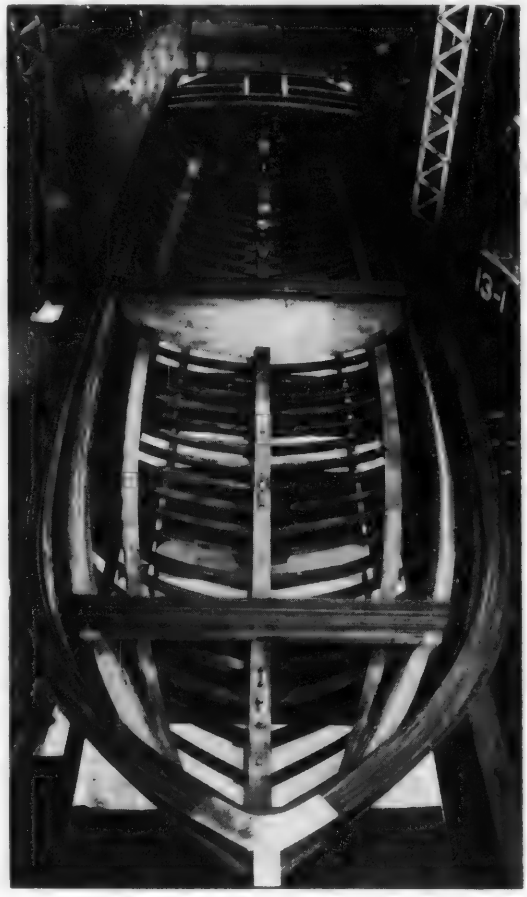

Fig. 1.—A forty-foot motor launch having completely laminated foundation including capping, deck frames, shaft log, stem, horn timber, and transom, fabricated at the Puget Sound Naval Shipyard Bremerton, Washington. (Official photograph, U. S. Navy.)

The Bureau of Ships may justly be proud of a part in this development, which is the first major contribution to wooden shipbuilding in 2,000 years. One of the Bureau's ship designers informed me that he scanned wooden shipbuilding literature from the era of Viking ships to the present in the drafting of the hull detail plans for a 165-foot wooden minesweeper. A volume published in 1863 on wooden ship design (7) describes methods evolved at the peak of large wooden ship construction, and represents accumulated knowledge from an almost forgotten generation of master boat builders and shipwrights working with the finest old growth

timbers. When such a reference book is again published, the Bureau's present laminated ship design will mark a new era in this field.

Adhesives for Marine Laminating

The intermediate and room-temperature-setting adhesives of phenol, melamine, or resorcinol base formulated for marine laminating are procured under Military Specification MIL–A–397.(*1*). Adhesives suppliers are required to submit proposed intermediate temperature setting, type II class 2, marine service adhesives for approval testing. These tests require approximately 35 days for completion and include 21-day accelerated cyclic-exposure and block shear tests of laminated white oak beams cured in accordance with manufacturers' instructions. Acceptance of a marine service adhesive is predicated on performance of test beams in comparison with Standards derived from extensive investigations, also complete physical and chemical evaluation of the adhesive with respect to composition, acidity limitations, cleanability, liquid working life, and storage life. A Qualified Products List is maintained of approved adhesives, in which the curing temperatures and curing period maintained at the innermost glue line for each manufacturer's type II class 2 adhesive is shown.

Laminating Techniques

Laminating procedures for white oak and for Douglas fir ship and boat members are described in specifications MIL–O–15154 (*2*) and MIL–F–2038 (*3*) respectively. These specifications list in detail the material requirements and closely controlled fabrication procedures and conditions which must be met and followed to produce acceptable prefabricated marine laminates of these species. A little less than 10 years of experience in laminating by several Naval shipyards and by private concerns specializing in laminated wood for naval construction have established the need for a relatively high temperature of cure to develop oak glue joints equal in strength to solid wood that resist delamination under extreme service conditions in sea-water (*4*). A number of phenolic-resin and melamine adhesives cured at 190° F. at the inner glue line for 10 hours, and resorcinol adhesives similarly cured at 140° F. for 10 hours have successfully resisted delamination in white oak beams as shown by several years service use, and by weathering and accelerated cyclic-exposure tests conducted at Naval Shipyards and at the U. S. Forest Products Laboratory. Douglas fir, southern pine, white ash, and similar woods having lower density than oak have been successfully glued for boat and ship timbers using resorcinol adhesives cured at somewhat lower temperatures, for the same curing period. Each type of adhesive and each species of wood to be glued must be related to a definite laminating procedure based on performance requirements. (*5*)

Laminating procedure specifications are being considered for such shipbuilding wood products as teak-Douglas fir decking, ash boat stock, scarfed long-length ship planking, and many other items procured by the Bureau. The research necessary to develop adequate material specifications is gaining momentum at many government, private, and institutional laboratories. Only through thorough, painstaking effort will this relatively young offspring of the forest products family grow into a modern progressive industry.

The challenges presented are worthy of the best technical skill we can summon. Primarily, these problems lie in the realm of wood preservation technology. Old growth timbers with their large proportion of durable heartwood for the shipwright's needs are fast becoming nostalgic memories. Research to determine means for suppressing and completely arresting deterioration of woods subject to extremes of decay, weathering and marine-borer attack is the key to wider acceptance of a great variety of domestic wood species as a structural shipbuilding material. Laminating has only unlocked the outer door to this problem.

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7. Murray, Andrew. 1863. Shipbuilding in Iron and Wood. Ed. 2, 166 pp., Illus. Edinburgh, Scotland.

Discussion

L. J. Jaworski (Borden Company): Is the present industry laminating capacity adequate for Bureau of Ships needs?

Mr. Kuenzel: Capacity is adequate for fir, not for oak. Some capacity is not situated favorable with regard transporting of large members to point of use.

J. M. Stevens (Bureau of Aeronautics, Dept. of the Navy): Is high frequency gluing presently being employed for curing marine laminates?

Mr. Kuenzel: For scarfing and pre-curing of glues—yes, by some of the larger laminators; for complete curing it is still in the developmental stage.

Dr. Frank B. Smith (Dow Chemical Company): How many of the 50,000 wooden ships built during World War II are still serviceable from a decay standpoint?

Mr. Kuenzel: In general, small boats that were stored indoors and larger ships placed in dehumidified storage are still in good condition; boats stored out of doors have required extensive overhaul. The British method of keeping wood boats and ships in service even though it means turning such vessels over to civilians has proved very satisfactory in that such vessels are seaworthy if and when required. A craft in use is better preserved than a craft in storage.

R. C. Fraunberger (Philco Corporation): We have been using two LCVP's for the last six years and I'm surprised that they have stood up as well as they have. We have had very little repair.

Mr. X: Are any adhesives other than those covered by Specification MIL–A–397 suitable for marine laminating?

Mr. Kuenzel: The urea adhesives proposed in World War II delaminated in salt water when used on white oak, and no modified or fortified materials other than those specified in MIL–A–397 have been tested sufficiently to justify their use in ship building.

Mr. X: Can wood treated, both for decay and for marine borer protection, be laminated?

Mr. Kuenzel: Yes, with proper preparation of material.

Selecting White Oak Trees for Bending Lumber

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Forest Service, U. S. Department of Agriculture

White oak for bending meeting Navy specifications was found to be produced from straight, well-formed trees of large oak, characterized by vigorous growth, a weight of not less than 40 pounds per cubic foot, and 6 to 15 annual rings per inch.

Introduction

BENDING oak for boat construction is a specialized material. Large amounts of bending lumber are needed in order to build and maintain the many small boats that are used by the Navy Department. Wood for this use must be strong, tough, suitable for bending to desired shapes, and relatively resistant to decay in exposed conditions. Inherent qualities of the wood in some species of the white oak group meet these requirements, and these species have been used with considerable success for a long time. Experience has shown, however, that certain pieces fail during the bending operations, thus causing appreciable losses in material and labor. In order to minimize the occurrence of failures during bending operations, the Forest Products Laboratory examined characteristics of white oak trees, logs, and lumber which were being supplied for bending purposes to the Navy Department according to its specifications.[2]

The purpose of the work was to summarize information on conditions of growth and kinds of trees that were being selected to supply material in accordance with the Navy Department specifications for bending oak.[2] Experience with some bending oak indicated that reasonable success in bending had been obtained by careful adherence to the specifications.

In cooperation with the Bureau of Ships, U. S. Navy, bending oak being produced on commercial operations was examined in the vicinity of Bluefield, W. Va., and also Shumm, O. This work was limited to procedures of selecting the trees and sawing the lumber to be offered for inspection for conformance with Navy Department specifications for bending oak.[2] Operations of the contractors supplying that material were visited, and the characteristics of the material were observed and discussed with the contractors. An over-all picture was obtained of the characteristics required in trees, logs, and lumber to meet specifications for bending oak.

[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2] Oak, white, and elm (for bending) Navy Department Specification 39–0–6c, Aug. 15, 1946.

Species and Site Conditions

White oak (*Quercus alba*) was preferred in West Virginia for bending material. In that locality, it was relatively free from the large worm holes caused by insects in the wood of some other species of the white oak group. Bur oak (*Q. macrocarpa*) usually was not considered suitable for bending in that area. Because of relative freedom from worm holes, however, vigorously growing bur oak in Ohio was generally considered equal to white oak. Bur oak in this locality was most common in low and moist places, while white oak frequently grew on the low knolls that were somewhat better drained.

Sites underlaid with limestone, and which often had loose limestone fragments on the surface, usually were considered favorable for trees from which to produce bending oak. Experiences of contractors supplying bending oak indicated that such sites produced vigorously growing trees that were relatively free from insect attack. On the other hand, soils which overlaid coal or mineral deposits in the West Virginia area frequently produced trees with poorer growth than did limestone soils. The lighter soils of Ohio, which occur frequently on low ridges, produced white oaks of poorer growth than did the heavier limestone soils. In general, sites with relatively deep and fertile soils having good drainage, which are commonly recognized as favorable to vigorous growth of hardwoods, were sought as sources of bending oak in both West Virginia and Ohio.

The stands of timber having oak trees large enough to produce bending stock usually contained a mixture of several hardwood species. White oak predominated in the West Virginia areas, along with some sugar maple, several red oak species, chestnut oak, and basswood. Bur and white oak were somewhat less frequent in stands of the Ohio areas than the red oaks, elm, sugar maple, basswood, white ash, and beech.

The topography of the West Virginia locality was exceedingly rough. White oak grew on sloping benches and in coves on the sides of the relatively low mountains of about 3,000 feet. In the Ohio locality, the land was approximately level, with only small differences in relative elevations between low

areas which frequently contained bur oak and only slightly higher areas on which white oak was more common.

Many of the trees that were large enough to produce bending stock in pieces 4½ inches square in cross section, were in relatively open stands. Some of these trees had remained in woodlots after other trees had been removed. Such stands were considered to be good sources of bending oak. Some of the stands were being heavily pastured, while in others restricted pasturing in recent years had permitted the growth of a considerable number of young forest trees.

Characteristics of Trees and Logs

Certain characteristics of individual trees are recognized as being essential to production of white oak lumber that can be bent successfully. On the basis of the contractors' previous experience, certain white oak trees were selected from which to produce the bending oak for the Navy Department contracts. In general, trees sought for bending-oak lumber had relatively large diameters at breast height, good form, straight grain, and vigorous growth. Trees with generally vigorous growth are necessary in order to obtain wood having between

Fig. 1.—This large white oak tree, grown in northwestern Ohio, has the desired external characteristics for bending oak.

Fig. 2.—A relatively small crown of a white oak tree with dead branch stubs that indicate a tree of poor vigor.

6 and 15 annual rings per inch and weighing not less than 40 pounds per cubic foot, as required by the Navy Department specification. Careful selection of trees from several woodlots is required since woods-run logs produce only limited quantities of bending lumber having the desired characteristics.

Size of Trees

Trees 20 inches and larger in diameter at breast height are necessary for production of bending-oak lumber in 4½-inch-squares, so that the size of trees suitable for this purpose is somewhat restricted. The age of trees selected for bending oak ranged from about 150 to 300 years. The largest white oaks observed in these studies were found in the Ohio locality, where occasional trees reached 40 inches in diameter at breast height. Fig. 1 shows a larger white oak tree grown in this area that had the characteristics that were considered desirable for bending oak. Most white oaks that were considered suitable for bending material in the West Virginia locality were between 20 and 30 inches in diameter.

Form of the Tree

Vigorous trees suitable for bending oak usually have large and symmetrical crowns that are characteristic of trees that have maintained dominant positions or have been grown essentially in the open. Stubs of dead branches and small crowns (Fig. 2), on the other hand, indicate less vigorous growth and often decadence of the trees. One-sided crowns also are undesirable because they indicate severe competition of the trees for light, water, and soil nutrients that are required for vigorous growth. Thus, size and shape of crowns and presence or absence of dead branches indicate whether trees are growing vigorously.

Straight and cylindrically shaped trunks also are desirable for production of bending oak lumber in order to minimize the amount of waste in sawing clear pieces with straight grain. Even large trees that have considerable taper are less desirable for bending oak than somewhat smaller ones with more nearly cylindrical trunks.

Surface Defects

The parts of white oak tree trunks to be used for bending lumber should be essentially free from live branches, knot stubs, and protuberances that indicate hidden defects. Profuse branching (Fig. 3) makes a tree entirely unsuitable for this use, since knots usually cause failure during the bending process. The presence of hidden knots frequently is indicated in large trees by overgrowths (Fig. 4) that often conceal knots completely. In addition, the grain in such overgrowths usually is distorted, so that it is likely to cause failure during bending even if an actual knot is absent from the piece cut out. The presence of knots close to the bark frequently is indicated by irregularities and small breaks in the bark (Fig. 5).

Fig. 3.—A tree with profuse branching that makes white oak unsuitable for bending lumber.

Fig. 4.—Overgrowth covering a knot on the side of a white oak log.

Only the first log of most trees was used for bending oak, since upper logs frequently had so many branches that no large, clear pieces of lumber were obtainable. Branches that are well distributed on all sides of the tree trunks made white oak undesirable for this use because of the difficulty of obtaining clear pieces in the lengths that are required. If, however, branches or stubs occur on only one side of the first logs, the clear sides of such logs often are suitable for bending lumber.

Spiral Grain

White oak trees with appreciable slopes of spiral grain are not satisfactory for bending oak because steep slopes of grain frequently cause failure during bending. A slope of grain of 1 in 15 is the maximum that is permitted by Navy specifications and obvious spiral grain in white oak trees usually exceeds that slope, so that they are not suitable for bending lumber. The presence of spiral grain can

Fig. 5.—A white oak tree with irregularities and small breaks in the bark that indicate hidden knots. Ridges and furrows of the bark follow a spiral course that indicates spiral grain on the wood.

be detected in standing trees by spiral arrangement of the ridges and furrows in the bark (Fig. 5) whereas in a straight-grained tree these are parallel to the longitudinal axis of the tree (Fig. 6).

Width of Annual Rings

Some general relationships are commonly recognized between properties of the wood and width of annual rings as measured by the number per radial inch. In hardwood species, such as oak, moderate to wide annual rings indicate average, and sometimes higher, specific gravity, a property that is a reasonably good index to the inherent strength of the wood.[3] Fig. 7 shows well-maintained specific gravity in an oak log having relatively uniform width of annual rings in comparison with reduced specific gravity correlated with reduced width of annual rings. Slowly grown white oak, as indicated by exceptionally narrow annual rings, usually is relatively weak and brash for the species.[4] Although there is no established relationship between brashness and bending properties of the wood, white oak wood

[3] Paul, Benson H., Application of Silviculture in Controlling the Specific Gravity of Wood. U. S. Dept. of Agr. Tech. Bull. No. 168. 1930.

[4] Koehler, Arthur, Causes of Brashness in Wood. U. S. Dept. of Agr. Tech. Bull. No. 342. 1933.

Fig. 6.—A white oak tree with straight grain that is indicated by the fact that the ridges and furrows in the bark are parallel to the longitudinal axis of the trunk.

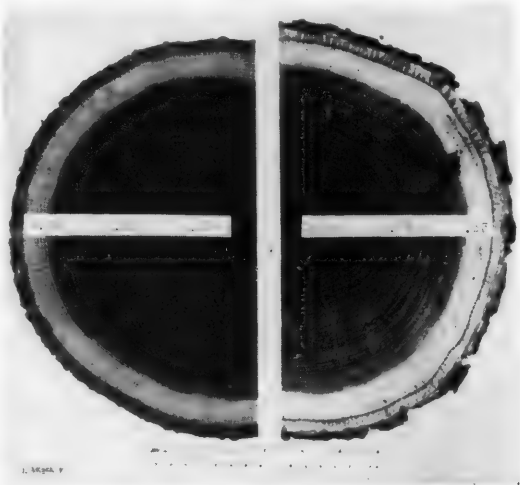

Fig. 7.—Relatively uniform specific gravity and width of annual rings (left) in comparison with reduced specific gravity correlated with reduction in width of annual rings (right) in cross sections of young oak trees.

with extremely narrow rings often fails in bending with crosswise buckling on the concave surface.[5] Thus, it appears that properties of the wood are related to its characteristics of structure, and thereby serve as guides for specifying and selecting material having qualities within established limits. For example, bending oak for the Navy Department "shall have not less than 6 nor more than 15 annual rings per inch of radius."[2]

Examinations of the ends showed that many of the logs selected for bending oak had 6 to 15 rings per radial inch.[2] In many logs, also, the annual rings were uniform in width, as indicated in Fig. 7 (left). Some logs and also some sawed lumber intended for this use, however, had as many as 20 to 25 rings per inch. An examination of log ends always should be made before bending lumber is sawed, because it is often not possible to detect narrow annual rings in standing trees. Because of earlier growth conditions, good-sized, young oak trees sometimes have been severely suppressed by surrounding trees long since gone from the stand. The effects of such suppression, however, had been recorded by zones of narrow rings.[3] Such zones of wood frequently have inferior toughness and poor bending quality. In other trees, however, with relatively narrow rings only at the center and with uniformly wider rings toward the bark, the wood frequently is dense and tough;[3] that is, it has the characteristics that appear to be closely related to good bending quality.

Bending-Oak Lumber

The production of bending-oak lumber requires careful sawing of the logs so that the saw cuts are made approximately parallel to the grain. To accomplish this, the logs that were sawed in West Virginia were slabbed with about 5- to 10-inch faces, depending on their diameter, with the slabbed surface as nearly parallel to the bark as possible (Fig. 8). Subsequently, 4½-inch cants were sawed parallel to that surface. Two saw cuts were made to produce two 4½-inch cants from each side of a 26-inch log that was free from knot defects. From smaller logs only one cant 4½ inches thick was sawed from each of two opposite sides of the logs, then pieces 4½ inches square were cut from the other two sides after the slab was removed (Fig. 8). The wide cants subsequently were ripped into as many pieces 4½ inches in cross section as possible, while the smaller pieces and the remainder of the logs were sawed into commercial lumber.

Examination of the bending-oak lumber being produced for the Navy Department showed that it was essentially free from knots and other defects that are not permitted for this use. Surface checks of a few pieces, however, indicated slopes of grain steeper than the 1-in-15 slope that is permitted by the specification (Fig. 9). Such pieces appeared to have originated from logs with spiral grain, which frequently can be detected by the direction of furrows and ridges in the bark of standing trees. Excessive slopes of grain and relatively narrow rings were the principal defects that were observed in bending-oak lumber.

Fig. 8.—Sawing bending oak from a 20-inch log showing (top) slabbed surface; (middle) side cant, and (bottom) two side cants and center flitch from which 4½-inch square pieces were cut.

Reports on yields of bending lumber indicated that logs with top diameters of 17 to 22 inches produced about 40 percent of their log scale as 4½-inch square bending stock. Logs with larger diameters were somewhat more economical to manufacture for this purpose, since their relative yield usually is higher than that of logs less than 24 inches in diameter at the top end. Logs smaller than about

[5] Peck, Edward C., Bending Solid Wood to Form. Forest Products Laboratory Rept. No. 1764. 1950.

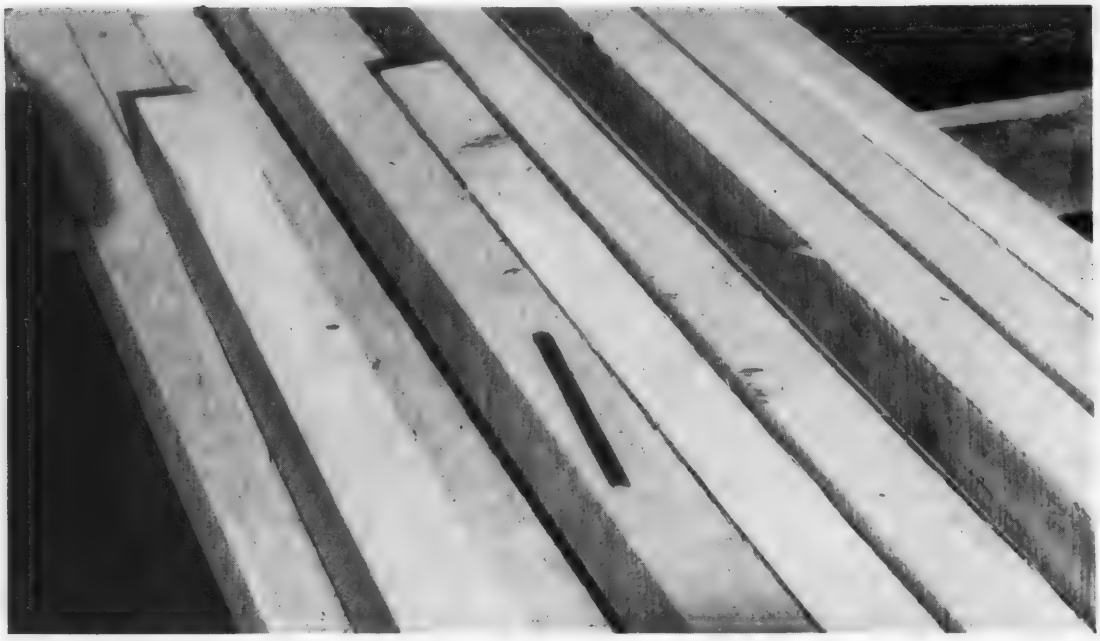

Fig. 9.—Pieces of bending-oak lumber. Position of rule indicates slope of grain steeper than 1 in 15 that probably resulted from spiral grain in the tree.

18 inches at the top end usually will not yield satisfactory bending lumber thicker than about 1 inch because of the lack of clear wood in such small logs.

The production of such a specialized material as bending lumber requires intelligent attention to characteristics of trees, logs, and lumber. Producers of this material should select trees (1) from sites having soil conditions favorable to vigorous growth, (2) having relatively long lengths free from branches and overgrown branch stubs, and (3) having straight grain as indicated by ridges on the bark which are parallel (not spiral) to the axis of the trunk. In addition, large trees should be selected, especially for bending lumber more than 2 inches thick, so as to obtain sufficiently clear material from the outer part of the trunk. Examination also should be made of log ends in order to obtain logs having between 6 and 15 annual rings per inch as required by Navy Department specification. Careful selection of trees and logs, with due regard to the need for avoiding visible defects and cross grain, will be helpful in producing white oak stock that is satisfactory for bending to the forms required for the Navy Department's small boats.

TECHNICAL SESSION IV—Wed., May 9, 1951, 9:00 A. M.

General Subject: New Machinery, Machining and Production Methods

Co-Sponsor: American Society of Mechanical Engineers, Wood Industries Division

Chairman: E. Sigurd Johnson—**Recorder:** F. F. Wangaard

Some Aspects of Wood Machinability Studies

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"Machinability of wood" is defined. The history of machining research and the current developments in this field are discussed. Several basic and applied studies of machining problems are briefly described, with particular reference to research at the University of Michigan. The Industry is urged to back further scientific investigation of machining.

What is Machinability?

ALTHOUGH the term "machinability" may be new, the qualities to which it refers are familiar to all wood processors. These qualities are the ability of a tool to cut and the ability of wood to be cut.

But what is there about these characteristics of tool and material which we call "machinability" that needs organized scientific attention? Is it not just a matter of production experience to know how different woods machine under certain conditions? The experience factor should certainly not be underestimated, but as a principal means of solving machining problems it is slow, inaccurate, and costly. Major advances in design and methods only occasionally originate by chance discovery of technical facts. Instead, they are the result of careful, methodical analysis of a problem beginning with its rudiments.

Historical Development

The scientfiic study of machinability is actually not very new. Metal processors have carried on intensive research in this field for more than 30 years. Their studies have resulted in almost unbelievable increases in the rate of production and the quality of machined metal parts.

Also a few pioneers in the woodworking field have been aware of the potential of machinability studies for some time. As far back as 1928 a committee was formed by the Wood Industries Division of the American Society of Mechanical Engineers to consider the possibility of reducing waste by improving the design and use of saws and knives. This distinguished committee, composed of ten prominent leaders of the woodworking and machinery industries, wrote an inspiring report which, except for some of the statistics, is as timely today as then (*1*). Among other things this committee recommended that the Society and the Industry give substantial financial support to a comprehensive machinability program. Unfortunately, this venture collapsed with the 1929 debacle and the farsighted objectives of the committee are still unrealized after 23 years.

Since this early beginning several relatively small, but nonetheless important, studies have been conducted both in this country and abroad. Kollmann of Germany in his "Technologie des Holzes" reports basic investigations of the theory of woodcutting by several German scientists (*8*). Harris of the British Forest Products Research Laboratory deals with some of the practical and theoretical aspects of machining wood in his "Handbook of Woodcutting (*6*). Foyster, also of England, has reported his findings (*5*). Other investigations have been made in Russia (*7*) and Japan (*11*).

In this country a modest amount of machinability research has been carried on in government and university laboratories and occasionally in an industrial plant. A study reported by E. M. Davis of the United States Forest Products Laboratory in 1942 dealt with some of the machining characteristics of certain hardwoods (*3*). The effects on surface quality of such factors as cutting angle, depth of cut, feed rate, cutterhead speed, moisture content, and knife jointing were investigated on an empirical basis.

Investigations of other aspects of machinability have been reported by Telford (*12*), Fleischer (*4*), Reineke (*10*), Patronsky (*9*) and others. These were for the most part analyses of regular shop processes by careful observation. Also included, however, has been some work on the basic theory of cutting wood.

Machinability Research at the University of Michigan

During the 1930's several introductory investigations of wood machining were made at the Wood Technology Laboratory of the University of Michigan. Although these studies were drastically limited in scope by lack of resources, reliable research techniques evolved plus a small fund of basic data.

Following World War II the University through the School of Natural Resources provided special funds for equipment of the type and quality needed for studying machinability on an increased scale. This installation was completed at the Wood Technology Laboratory during 1948. In 1949 the

Kroehler Foundation of Naperville, Illinois, established a trust fund which made it possible to add a technologist to the staff for full concentration on machinability research. In the ensuing program studies have been made of several of the basic factors of machinability, including surface quality, energy requirements, kinematics of cutting, and others. In addition to these, several specific industrial problems have been analyzed.

In this research in machinability a double-barreled approach—to combine the theoretical and the practical—has been attempted. The basic factors of machining, few of which are now understood, must be sought out. The writers are also convinced, however, that many practical problems demand the attention of intensive organized research. To neglect the practical urgencies of the moment while we ferret out fundamentals would be unrealistic. On the other hand we can expect only limited progress in solving everyday machining problems without the necessary depth in background information. The individual phases of machinability which have been studied recently at the Wood Technology Laboratory include some of the most basic aspects of woodcutting on one hand and aspects which are taken directly from industrial applications on the other.

Physical and Structural Properties of Wood and Machining

An advanced graduate student in wood technology is now investigating the relationship between the structure of wood and the way it cuts. This is one of many fundamental factors affecting machining processes which are virtually unknown. An effort is being made to link up the various structural and physical properties of wood itself with its capacity to be machined. It is known that certain species machine better under given conditions than others and that such structural features as direction of grain with respect to the direction of feed have an important effect upon the quality of machining. Intuitive knowledge of these effects is not enough, however, to tell us just why one species cuts more easily than another or what we can do about machining wood with distorted grain. These facts lie hidden in the basic mechanics of the wood and the cutting tool. The tools necessary for a study of this kind are not a modern production molder or a straight line rip saw but the microtome and the microscope.

Kinematics of Tools

Another investigation of fundamentals which has been found interesting and enlightening is a study of the kinematics of tool paths or the motion of the cutter as it travels through the wood. Saw teeth or planer blades are ordinarily thought of as traveling in a circle, and in relation to their own axes, this is true. Their relative path in stock which itself has linear motion is quite a different matter, however. This subject came to our attention in determining the nature of knife marks in rotary cutting. This subject was itself suggested by the problem of grinding multiple knives to cut in the same circle.

The theoretical height of the "peaks" left by rotating knives as the stock travels past them was computed, and it was found that for ordinary conditions of cutterhead speed and feed rate the height of these peaks is extremely small. Assuming that all knives cut equally, these peaks have a height of only a few hundred-thousandths of an inch. This dimension may be found from the equation

$$h = \frac{r}{8}\left(\frac{1}{mr + \frac{k}{2\pi}}\right)^2$$

where, h = height of "peaks" or knife marks in inches
r = radius of cutting circle in inches
m = number of knife marks per inch computed from speed and feed
k = number of knives

If as an example, we assume a cutting circle of 3-inch radius, 4-knife cutterhead, and conditions of feed and speed which should theoretically give us 30 marks to the inch, the solution would be

$$h = \frac{3}{8}\left(\frac{1}{30 \times 3 + \frac{4}{2\pi}}\right)^2$$

$$= 0.000045 \text{ inch}$$

Such small dimensions suggest that the marks we ordinarily see can be the product of other factors, such as eccentric spindle rotation or poorly fitted knives. Further analysis of this problem may show that improving the dynamic balance of the cutterhead or the precision with which knives can be fitted will greatly reduce such practical considerations as the sanding necessary to remove knife marks.

Energy Requirements of Cutting

Another productive field of investigation has been the energy or power required in cutting. This may be approached in two ways—either by measuring the forces required to remove the individual chip with a precise dynamometer, as has been done by Reineke (*10*), or by measuring the energy conversion which takes place in a machine operating under given conditions.

An example of the latter is a study which was made at the Laboratory of the relative energy requirements of 3 different circular rip saws. In this study the net horsepower requirements of the three saws were determined under various conditions from a recording wattmeter in the saw motor circuit. The relative effectiveness of the saws was calculated in terms of efficiency of removing material, or, the cubic inches of material which could be removed per

minute of operation per horsepower required. This relationship is expressed by the equation

$$E = \frac{w \times d \times f}{P_m}$$

where, E = efficiency of removing material (cu. in. per min. per hp.)
w = width of cut or saw kerf in inches
d = depth of cut or thickness of stock in inches
f = feed rate (in. per min.)
P_m = net power delivered to motor (hp.)

As an example, one saw had a kerf of 0.15 inch, the thickness of the stock was 1.22 inches, and it was found that for a feed of 57 feet per minute (684 inches per minute) an average of 3.08 net horsepower was required. E can be computed as follows:

$$E = \frac{0.15 \text{ in.} \times 1.22 \text{ in.} \times 684 \text{ in. per min.}}{3.1 \text{ hp.}}$$

$$= \frac{123.1}{3.1}$$

$$= 39.7 \text{ cu. in. per min. per hp.}$$

By comparison the other two saws, which were of different design, gave values of 26.4 and 29.8 cu. in. per min. per hp.

The application of this concept of power rate is new in woodworking practice, although it has been used in an analogous way in metalworking for several years. Efficiency may be thought of as a means of combining power requirements and productive output in a single term, avoiding cumbersome relationships which are difficult to visualize.

Since removing material is the basic aim of any machining operation, it can be seen that efficiency with which the removal is performed is a practical rating. Almost any machining process may be analyzed in this way to determine the most favorable conditions of operation.

Cutting Condition and Design of Tools

Studies of cutting efficiency automatically lead to a consideration of the effect of the design and condition of the cutting tool upon this efficiency. Such terms as "sharp edge", "right cutting angle", or "proper clearance" need to be clarified and given quantitative meaning.

We all have some idea of what a "sharp" knife is. But just what are the various attributes which constitute "sharpness" and how can they be measured? We have analyzed some of these ambiguous terms and believe some progress has been made in defining them.

For instance, it is tentatively assumed that "sharpness" is a function of the following independently measurable factors: (1) Continuity of the cutting edge, (2) The surface roughness of the face of the cutter, (3) The surface roughness of the back bevel of the cutter, (4) The width of land formed along the edge by wear or jointing, (5) The sharpness angle.

It has been possible to measure the continuity of the edge and the surface roughness of the bevels by means of an electronic analyzer which determines the average roughness within an accuracy of a few microinches. The land formed along the edge can be measured with considerable accuracy by means of a calibrated microscope. The sharpness angle can be determined either by an optical comparator or a vernier protractor. With further study we hope to be able to correlate these factors on the basis of their relative effect upon cutting and thereby assign actual values to "sharpness."

Analysis of Surface Quality

As is shown above, one of the most difficult problems in making analyses of machinability is that of providing suitable means of measurement. This is certainly true in the case of analyzing the quality of machined surfaces.

The part which well-machined surfaces play in gluing and finishing has become increasingly evident in recent years. These questions arise repeatedly. How do we know when a surface is smooth enough for finishing, or how can we tell when we have machined a surface satisfactorily for gluing? When has machining under one set of conditions produced a better surface than under another?

The pressure of such problems has caused researchers to seek an objective means of evaluating surface quality. Various methods have been tried. Davis (3) and others have used a systematic procedure of visual inspection, and for many purposes this is probably the most practical method yet devised. Any visual method depends much on the judgment of the inspector, however, and can at best be used only to distinguish the gross defects produced under various cutting conditions.

Fig. 1 shows representative pieces of stock which were machined on a shaper. Five different cutting angles were used as shown. The difference in the quality of these surfaces is visually apparent, but it is extremely difficult to rate them quantitatively. Evaluation of these differences by measuring differential light reflection or the varying density of a photographic negative has also been investigated.

In addition to the methods of surface analysis described above, various mechanical methods have also been used. At the Forest Products Laboratory the roughness of rotary cut veneer has been estimated by measuring the thickness of a small sample to the nearest thousandth of an inch at selected points. The degree of variation in thickness gives an approximate evaluation of roughness. Some success has been achieved using the type of electronic surface analyzers normally used to evaluate metal, glass, plastic, and ceramic surfaces (9). These instruments, which employ a sensitive stylus, are capable of measuring the average height of surface

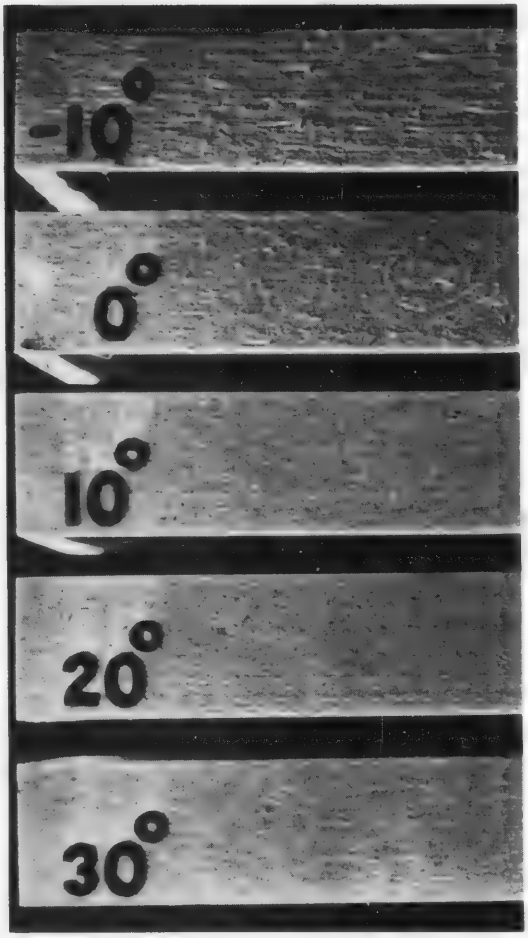

Fig. 1.—Effect of variation of cutting angle on surface quality in shaping aspen.

irregularities to the millionth of an inch. The range of irregularities in wood surfaces is so much greater than in the materials for which these instruments are designed, however, that numerous difficulties are encountered.

The problem of surface analysis is sufficiently important to warrant much greater attention than it has yet received. In practical application a usable method of determining surface roughness would be an invaluable tool in quality control and would lead to a solution of many current quandaries over machining and sanding techniques.

Machinability Related to Production Processes

Principal efforts in machinability research at the Wood Technology Laboratory have dealt with production processes such as planing, sawing, and shaping. The conditions under which these studies have been conducted are generally analogous to plant conditions, with the exception that the factors which are extraneous to the measured data must be very closely controlled.

To conduct this type of investigation, it is necessary to have standard production machines which can perform the basic machining operations. These also must be adapted to cover a wide range of conditions. Equally important are such auxiliary facilities as a dry kiln and moisture conditioning rooms for preparing and controlling research material, a machine shop for fabricating special devices, and many types of precision instruments for observing machine performance and behavior of materials.

Over a period of several years facilities of this sort have been installed by the School of Natural Resources at the Wood Technology Laboratory for undergraduate instruction and graduate research. Since the use of the equipment in this capacity is only partial or intermittent, it has been desirable to make it available for additional faculty-supervised research. Such research has included several projects of considerable scope.

One major program has been conducted in cooperation with a manufacturer of planers. In this program several of the basic factors of planing were considered. Some critical features of machine design were also studied in an attempt to improve the sponsor's product.

Under way at the present time is a study of rotary cutting in which the effects of cutting angle and grain direction are being investigated for several commercial woods. A shaper is being used for this work since it is the most primary of all machines using the rotary cutting principle. It offers further advantages in ease of observation and ease of setting up the desired conditions. Fig. 2 shows some of the preliminary work of this study in progress. The speed of the cutterhead while cutting is being

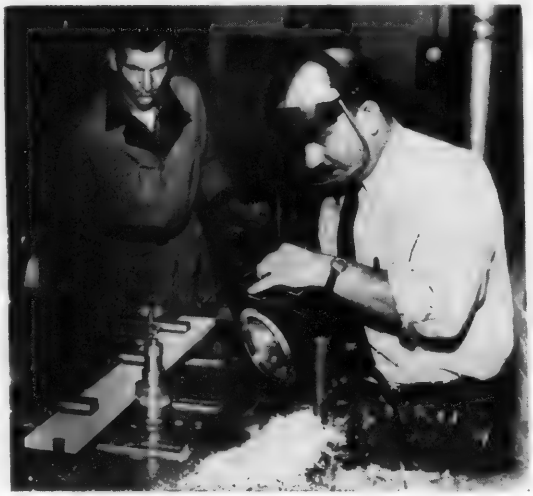

Fig. 2.—Machinability study of a shaper operation.

checked by means of a stroboscope (instrument at right). The power required is graphed by a recording wattmeter (at left). The stock clamped in the carriage is fed at a constant rate toward the operator at the rear. Among the essential features of this set-up are a variable speed motor for feeding the stock and a variable speed drive for the cutterhead. Since it would be extremely costly to supply a variable drive on all machines which are used for such research, a frequency converter has been installed which provides variable frequencies up to 130 cycles per second. This makes it possible to obtain any speed up to more than double the rated speed of the motor at 60 cycles per second.

Flexible, yet precise, facilities of the type described above are almost mandatory in studying machining processes. This opinion is based upon many years of experience with makeshift arrangements which provided neither the accuracy nor the convenience essential to major machinability research. That adequate facilities have been made available at the University of Michigan and other publicly supported institutions is a momentous advance. It is now up to the woodworking industry to take full advantage of these resources.

The Outlook for Machinability Research

With a large part of the necessary physical plant already available it is only a short step to the establishment of a sound, co-ordinated program of machinability research. This program would help meet not only the urgent needs of the moment but would also supply the foundation for general technical advancement in the future.

A successful research organization has many of the same ingredients as a successful manufacturing venture. Running a research project without sufficient technical manpower is as inconceivable as operating an industrial plant without a managerial staff. Yet, at the various publicly-supported laboratories only a very few technologists and research engineers are available for concentration on wood machining problems.

Mr. R. D. Brooks, in a paper presented before the American Society of Mechanical Engineers (2) has pointed out some of the opportunities and responsibilities of the Industry to study the use of carbide tools in woodworking. Although Mr. Brooks discusses a specific subject for investigation, we believe that his reasoning is valid for all phases of machining. He says, "There are four groups who are, or should be, vitally interested in the ultimate success of carbide tools in the woodworking field: (1) the producer of carbides, (2) the fabricator of the carbide tools, (3) the manufacturer of the woodworking machinery, (4) the user or consumer of these tools and equipment.

We believe that these four groups which are vitally concerned with wood machining should either as individual companies or through their associations lend financial support to research from which they will each derive benefits. For maximum effectiveness it is suggested that this support be in the form of trust funds or research fellowships. Such a cooperative program certainly should not impose an undue burden upon individual firms and would make it possible to disseminate widely the results of machinability research in a manner similar to that now used by the United States Forest Products Laboratory.

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Where and How to Use and Maintain Carbide Cutting Tools in the Wood Industry

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Tungsten carbide tools have numerous applications in the woodworking industry, especially on cutting jobs where dulling of tools is rapid. Proper tool maintenance is a desirable and very profitable adjunct of carbide-equipped plants.

MACHINING wood is a basic job in the wood industry, as well as one of the most expensive operations. Machinery and cutting tools are costly, and workers must be skilled. For many years the machinery manufacturers, engineers, factory managers, and the industry, as a whole, have ignored the stagnation of this important phase of woodworking. Now, due to the acceptability of tungsten carbide tools, the industry has awakened from its hibernation. The machinery builders are now actively planning and designing machines with the cutting tool foremost in their minds. Machines are, and will be available, with dynamically balanced spindles, more accurate tool mountings, greater spindle speeds, and increased horsepower.

In this discussion of tungsten carbide, let us bear in mind that its greatest difference, from high speed steel, is that the carbide is harder, and therefore, more resistant to wear. The high concentration of tungsten and cobalt, necessary in the manufacture of this diamond-hard material, causes it to be expensive. We cannot, however, always justify the excessive cost of carbide tooling. In most applications, cost is a limiting factor. But in a great many applications, initial cost is not always the greatest expense. The most distressing, and perhaps the greatest expense of tungsten carbide tooling, is mishandling, improper grinding, and the delay and expense in mailing when it is necessary to return tools to the tool manufacturer for re-grinding.

Where Carbide Fits In

Carbide is a must in many cases. When working with synthetic materials, laminated wood products, and second growth woods which carry mineral streaks, or in applications where high speed steel will not hold an edge more than a few hours, its value is unchallenged. Carbides can and should be used in every application where savings can be realized, after comparing its initial cost, and the cost of maintenance, with your present high speed steel applications, with emphasis on maintaining the quality of the work.

On this basis, for a shop of medium size and larger, the use of cemented carbide is recommended for the following:

A. On planers and hand jointers under 6 inches in width.
B. On automatic edge jointers.
C. On moulders and shapers for all straight knife heads. Also on profile heads when abrasive materials are to be machined, or when a set of knives will be re-sharpened more than 20 times in the life span of the shape. Cemented carbide profile heads for shapers and moulders can, in many cases, be purchased for only a little more than a set of high speed steel knives. This provides the advantage of an additional tool, and eliminates the cost and delay of mounting knives in individual heads.
D. On router machines; straight cutters, where length of cut is not excessive. On profile shapes, where abrasive materials or glue lines are encountered.
E. On saw operations.
In practically 90 percent of saw applications, carbide tipped saws can be profitably used. Caution should be exercised in very fine tooth cut off operations.

Care and Maintenance

To experience any real success with the use of tungsten carbide, proper maintenance and care in handling must be practiced. The position of the wood industry today, relative to the care and maintenance of carbides, is an exact duplicate of the metal industry in 1934, where no headway in its use was made until it had developed and trained men in controlled grinding procedures. These men in turn spread its correct care and use throughout the shop. As a result, the metal working machine tools of today are designed around cemented carbide tooling.

If the industry were denied the use of carbide, our present defense effort would be seriously handi-

capped and there would be a considerable increase in the price of its products.

Let us review briefly what an intelligent, well trained person in charge of tool maintenance could do for your plant.

1. Discontinue the purchase of 110 different types of saws in favor of approximately 12 well chosen sizes and tooth ranges.
2. Have moulder heads properly ground with correct profiles and clearance angles, ready to mount and run on the moulder, thus eliminating 65 percent of the machine down time.
3. Have shaper cutters properly made and available when needed.
4. Supply you with the proper tools, correctly ground, available for the job at the right time. This should promote approximately a 90 percent reduction in the expense of delay.

It is the writer's opinion that a great many of the plant managers are unaware of the high cost of an unregulated tool maintenance shop.

There is really nothing complicated or unusual about handling tungsten carbide tools. The ordinary care given any type of precision cutting tool is sufficient. Rough treatment or careless abuse will result in dulled or chipped cutting edges. Damage to cutters, such as chipping, and sometimes breakage, which appears after a run, is in most cases caused by careless handling when mounting the tool in the spindle. Best results in protecting carbide tools are obtained by instruction, and supplying suitable carrying cases with instruction for the proper care and use of the tools. These instructions are available from competent tool manufacturers. It has been found that capable operators, properly instructed on the use of carbide tools, have been the most enthusiastic promoters of the program.

Proper grinding, done at the right time will do more than anything else to prolong the life of carbide tools. More dulling occurs in the last 20 percent of the useful life between grindings than in the other 80 percent of its use. If a grinding schedule is set up so that a tool can be re-ground before dulling to the extent of indicating poor finish, chipping, or tear outs, it will be possible to restore the keen cutting edge by the removal of .002 inch to .004 inch rather than the .006 inch to .012 inch necessary when utilizing the last 20 percent. As you can see, a regulated grinding schedule will result in ⅔ greater tool life, and maintain higher product quality.

When grinding cemented carbide a diamond wheel of 100 grit or finer should be used, mounted on a dynamically balanced precision spindle, running at about 5,000 surface feet per minute. Not more than one-half of 0.001 of an inch of carbide should be removed per pass of the tool across the wheel.

Since carbide tools cannot successfully be jointed, good grinding equipment should be used to assure accurate results. Care should be exercised so that the tool is set in the same relation to the wheel as previously ground to maintain the same cutting or clearance angles.

If proper equipment is available, and tools are not abused, regrinding costs should be no more than on comparative high speed steel tools.

Centralized Tool Control

To really benefit by the saving afforded by use of cemented carbide tools, each plant should have a central grinding department, with equipment and know how to properly maintain all the carbide tools used in its operations. In shops of medium size and larger, it has been proven that tool maintenance costs can be substantially reduced with an increased carbide tool program.

Discussion

E. Sigurd Johnson (North Carolina State College): Straight line rip saw—should kerf be increased for carbide vs high speed?

Mr. Flinchbaugh: Usually reaction is "kerf too wide." Overlook that with 13 gauge steel but due to set kerf in carbide, is actually, if anything, less than with steel.

R. D. Brooks (Firth Sterling Steel & Carbide Corporation): This question is somewhat misleading. The term high speed could refer to high arbor speeds, high material feed rate, or to the ambiguous term—high speed steel. Considering these in order, it is our belief that:

High arbor speeds are generally accepted as an aid to blade rigidity. This speed would, under good to excellent operating conditions, allow use of a thinner blade. The key here is the accuracy of the operating machinery, the saw itself and the conditions under which this equipment and its operators must produce.

High speed material feed—if material is fed into a saw at an increased rate while its speed and tooth spacing remain the same, a greater chip load per tooth will result. This increased chip load will produce additional strain on the rim of the blade. This increased load may be compensated for by either of two methods—(1) increasing the number of teeth or (2) increasing arbor speeds to bring more teeth into the cut for each foot of material feed. Under this latter condition, it would be possible to reduce the kerf of the saw.

This use of high speed, often referring to the type steel used in the manufacture of wood-cutting

saws is a misnomer. High speed steel is rarely used to manufacture wood-cutting saws. They cannot be set and, when hollow ground for clearance, require extreme care in resharpening.

In conclusion, it is possible, and it is general practice, to provide less initial clearance on a carbide tipped saw than on a set or swaged saw. Standard clearances will average .045 to .050 inch. This is possible with carbide tips, as they do not lose the sharp point clearance as rapidly as the carbon steel saw with its needle points.

John Griffith (Mississippi Products Inc.): Has equipment been placed on the market for replacing carbide inserts in saws?

Mr. Flinchbaugh: Substantial investment in grinding and brazing equipment and about three saws per machine are suggested if factory maintenance is practiced.

Mr. Brooks: Basically, all that is required to replace carbide tips are: brazing torch, flux, silver solder and considerable skill, craftsmanship and experience on the part of the mechanic. Once the tip is brazed in place, it must be ground on the face, top and both sides to line up with the remaining teeth. This grinding requires the use of a substantial and accurate tool and cutter grinder and a diamond wheel of the correct grade. These two processes appear simple enough, but are complicated by a number of conditions. The application of heat must be carefully controlled to prevent distortion of the steel plate. Perhaps the ultimate solution will be sections, with brazed carbide teeth, which can be mechanically held and adjusted in the plate.

Mr. Griffith: Have carbide tipped saws proven satisfactory on ripping operation on continuous core gluing machines such as Taylor or Plycor?

Mr. Flinchbaugh: Automatic cut-off applies considerable side pressure on saws but there are several successful applications. Much depends on balance of the saw.

Mr. Brooks: Where the material is being fed at the same time as the saw is cutting across, there will be pressure. This has been compensated for on some equipment by either of two methods: (1) arrangement for advancing the saw assembly at the speed of travel of the material such as is used in cutting insulation board blanket, or (2) momentarily halting the flow for the saw to travel across and lifting the saw for the transverse travel.

Mr. Griffith: How can side pressure develop in Taylor gluing machine?

Mr. Flinchbaugh: If constant ratio is held, there will be none.

Davis R. Godwin (Atlantic Plywood Corporation): How do you qualify a woodworking plant as to medium or large in size?

Mr. Flinchbaugh: Basis is number of machines rather than number of men employed.

Joseph Paul (Phenix Manufacturing Company): How can carbide tools be used in shops with only semi-skilled labor?

Mr. Flinchbaugh: We recommend the training of an individual, preferably someone from the tool maintenance department, on the use and care of carbide tools, with emphasis on the economical application of carbide. The Redco Tool Company has set up a training program of this type, which we offer to the users of the Redco grinders as an added service.

The training, covering a period of one week, is done in our plant, with some instruction on applications in the wood shop. In the training program they are not only instructed, but they must be able to grind all types of tungsten carbide tools along with profile knives for moulders and shapers.

Paul R. Kramer (Texas Forest Service): What has been the experience of oak flooring mills using carbide tipped saws, particularly on rough end ripping operations and on gang ripping.

Mr. Flinchbaugh: Carbide tipped saws are not always used economically in oak flooring mills for several reasons. Considerable work must be done in the training of personnel in the use of carbide tools along with definite re-sharpening schedules. Also, in many operations, the type equipment does not lend itself to gang ripping with carbide saws.

Frank R. Palmer (Palmer Machinery Company): What data are available to show economies of carbide vs. high speed steel operation and maintenance?

Mr. Flinchbaugh: No specific data at hand. Saving (average) of 6–10 times in maintenance.

W. Burdette Wilkins: This subject was discussed at our Annual Meeting in March, 1948 in a paper written by Harry Crump of the Carbaloy Company and presented by Mr. Gillespie of the same company. The subject was discussed at some length and is recorded in our 1948 Proceedings. Also, this was discussed at the Northeast Section Meeting at Chicopee and is reported in the Northeast Sectional Proceedings of that meeting.

B. M. Baker (Grand Rapids Chair Co.): How thin a saw kerf is obtainable with carbide?

Mr. Flinchbaugh: 1/10 inch kerf is the narrowest kerf. Ordinarily only 5/32 inch. It is limited by support for carbide and tensioning requirements.

Mr. Brooks: Carbide tipped saws of 1/8 inch kerf are regularly advertised and supplied which produce satisfactory work. There are isolated cases where saws with kerf as low as .062 inch have been supplied for special grooving work. Experience indicates that thin saws require higher arbor speeds to aid in maintaining tooth alignment. With increased arbor speeds, the number of teeth decreases.

Machines with very accurate arbors and feeding mechanisms, plus higher arbor speeds, offer the best conditions for operating thin kerf blades. The thin kerf saw should be held to the minimum diameter or designed as a thin-rim saw to cut material of specific thickness.

Roswell D. Carpenter (Southern Forest Experiment Station): You state that machines will be

available with dynamically balanced spindles. What do you recommend doing with machines that we presently own in order to make them perform well enough to handle precision ground, dynamically balanced cutting tools?

Mr. Flinchbaugh: Spindles in old equipment can be reconditioned and dynamically balanced, which will result in greater bearing life, and an improved finish. This is only recommended, however, when the age of the machine, or its condition, justifies the necessary reconditioning expense.

G. A. Johnson (Mattison Machine Works): Many machines of ball bearing type now being used will handle dynamically balanced cutting tools and give good results under certain conditions. It is questionable whether this is possible with multiple knife heads such as are used on a moulder. This subject has unlimited technical phases and would require a very lengthy paper to cover all machines and phases, therefore, it would seem each case and machine would have to be considered as an individual job.

William F. LaKamp (Baldwin Company): We have difficulties in sawing Mangus Sonora woods. We have tried carbide tipped saws and high speed steel saws with various settings of teeth. The teeth seem to lose their cutting edge very quickly. We use Diehl straight line rip saws and cabinet saws. What can we do?

Mr. Flinchbaugh: Carbide tipped saws should perform satisfactorily on sawing Mangus Sonora woods on a Diehl self-feed rip saw. The pitch of the teeth will depend entirely on the type finish required. Sometimes difficulty is experienced on the Diehl saw when using it in a trimming operation when a sliver wedges between the saw and the chain, driving the saw against the cast iron chain teeth, causing damage to the saw.

William C. Hunt (National Homes Corporation): The general trend of remarks on the paper seem to be against the use of carbide saws on gang rip saws. I would like more information on this use of carbide with the results of any experimentation along this line.

Mr. Flinchbaugh: Carbide saws can be used on gang ripping operations, but not always economically. The greatest difficulty is the abnormal chipping of teeth, which is caused by one saw working against the other, and some times due to inferior hold down equipment. We would recommend a coarse tooth rip saw of heavy gage for gang ripping operations.

Mr. Brooks: The throat through which the saws are run must be flat and flush with the table. This will eliminate the pounding action of the board as it is pulled downward by the saw teeth only to spring back again. Rotary splitters behind each saw to aid in keeping the individual pieces in line are valuable. Flat or roller spring hold-downs for each piece are required. Alignment of saw arbor, feed rolls and rip fence must be accurately adjusted to prevent binding. Increased arbor speeds with less teeth per saw have proven more satisfactory. This has been demonstrated in cutting white pine sash stock and wet elm and cottonwood basket slats. Wire bound box cleats have been successfully cut with 12 inch saws having 12 teeth per inch. The saws have 30° hook ground with square faces and tops. Arbor speed was 4200 R.P.M.

Other conditions affecting good saw operations are: Condition of material to be ripped. Rough, cup or twisted boards cause considerable trouble when using standard steel saws. The wide variation in flexibility between carbide and carbon steel accounts for many of the fractures that occur. The steel plate will bend, but the carbide, because of its stiffness, will fracture. Carbide tipped saws have been used successfully where the material has been surfaced (preferably on both sides) and each piece is held in contact with the table until it has cleared the saws.

This brief, generalized reply to Mr. Hunt's question is by no means complete. There are several carbide saw manufacturers who would be willing to go into this problem more completely.

Progress in Industry Through the Use of Carbides

ERIC T. ROTHLEY, *Vice President, Big Four Carbide Tool Co., Cincinnati, Ohio*

Carbide-tipped woodworking equipment offers the woodworking industry the benefits of increased production at costs lowered because of less down time for sharpening and improved quality of work. Failure of carbides to give immediate satisfaction in some cases can be traced to their installation in defective machines. The profitable extension of the use of carbides should be a joint undertaking of machine tool builders, cutting tool manufacturers, and wood fabricating shops.

TUNGSTEN carbide is in truth a miracle name. It refers to a man-made substance that is next to the diamond on the hardness scale. Tungsten carbide, or just plain "carbide" as it is most commonly referred to, has been known to high production shops for upwards of 25 years. Its use today is extensive in metal working shops, but the woodworking shops as a whole have yet to grasp this means of greater output.

Practically everyone with shop experience has heard or read of Tungsten carbide. In some isolated cases carbides are still erroneously associated with the old gas generated illuminating light. In olden days it was used to "light the way". Today we can use carbide to "light the way to higher output with lower unit costs". But we have a long and dark path to follow before the maximum can be obtained.

Progressive shops have tried carbides on one or more applications with generally good success. The mediocre and small shops have yet to "form the carbide habit" because of poor initial results, refusal on part of employees, outmoded thoughts of management, or because of lack of capital.

Carbides in War Efforts

Carbides and their correct application in the metal trades probably did more to win the last war than any other single production item. This is factual from the many case histories conducted by production engineers, time study and methods departments, and machine tool builders. A single application may be cited to point out the value of carbides in this field.

While the B-29 of war and present fame was still on the drawing board, some shops were engaged in manufacturing parts for it. In a western shop great difficulty was experienced in milling a part for the landing gear assembly. Fifty-eight milling machines working three shifts daily were engaged. The material was so tough, hard to mill, and production so low, that the Air Corps was constantly at management's throat. Production for the three daily shifts on the 58 mills was only 58 parts. To help break this bottleneck, it was decided to take the problem to a machine tool builder. After an investigation, some changes in fixtures and jigs were made, milling machines and carbide tipped milling cutters were especially designed and employed. The results were unbelievable. Eight mills so prepared, actually out-produced the original 58. The milled pieces had cleaner finishes and dimensions were more closely held.

The good results of carbide application by the metal trades can be duplicated in the woodworking field if sufficient interest can be aroused by machine tool builders, cutting tool manufacturers, and production shops. Actually it took a world war that placed our very lives in danger to shake the lethargy from the metal trades. When it became obvious that the production of war material would have to be speeded to catch up with the enemy who had had years of war production, a definite turn to carbide was made.

Naturally we do not want another war to shake us out of our lethargy, but some means must be taken so that the advantages of carbide can be successfully enjoyed.

Co-operation for Progress

Aside from the consumer who pays the bill, there are three groups in this industry who can, if interested, work together for the mutual advantages obtained by the successful use of carbides. These groups are the machine tool builders, the cutting tool manufacturers, and the wood fabricating shops. Neither one of these, no matter how strong his desire, can accomplish the job by himself. Experience, ingenuity, the pooling of technical knowledge, and application are equally important one to the other. Each factor is so dependent on the other that success can only come by wholehearted co-operation.

You may ask "Why should I get excited about carbides? What will it mean to me? How much is it going to cost? How will I profit?" One statement may be given for all these questions. It follows: One must take advantage of every modern method of production. If he doesn't, his competitors, with their methods, will force him to lower his selling prices, which in turn will reduce his profits. Without a legitimate profit, he will have to close his doors.

The writer is engaged in manufacturing carbide tipped cutting tools, and would like to manufacture just as many as possible. However, if he and his associates were not making carbide tools, they would be making high speed tools, so increasing carbide volume as such is not the objective of this paper. Rather the advantages of carbides to industry, the modernization of shops, and the increase of profits to industry as a whole, have prompted its presentation.

Many of our operations, and in fact the whole production of many shops, remain the same today as when grandfather founded the business. This isn't progress, this is only hanging on. These shops rarely offer competition to anyone. How can such a shop compete with a modern shop? Think of the quality and cost for a moment, if automobiles were made today as in grandfather's day.

To swing the metal trades to carbide, pressure was brought to bear by the production shops. They presented their problems to the machine tool builder. He responded, and in many cases, built special machines. In woodworking, in some instances, this has also been done. The majority of plants, however, have to be sold on a better machine or an improved method. Rarely do you find a shop buying. It seems therefore that perhaps the woodworking machinery builders and the cutting tool manufacturers must take the initiative. They should devote a share of their employees and capital to research. From this will come better machines, better methods, and a modernization, which will be felt industry wise.

Carbides for Glue Line Ripping

For the uninitiated, it may be well to present a few examples of typical carbide productivity in woodworking. It would be safe to say that when steel blades are used for glue joint ripping, only a jointed blade is satisfactory. The length of time this blade will remain sharp is known. Generally a day is a long time, more often it must be removed sooner, depending of course on stock and feed rates used. By contrast, a carbide tipped rip saw blade will last for weeks, months, and some have been known to successfully cut glue joints after 14 months of continuous daily production. Admittedly this is an exception and not the rule. Generally speaking if care is used in putting a blade on the saw, and judgment exercised in feeding, carbides on average stock will go 40 to 60 times over steel. The writer knows of one application where carbide tipped rip saw blades repeatedly produce 280 times more work between grinds than any steel blade previously used. Incidentally on this application, when the steel blades became dull, they cracked. This has not happened with the carbide tipped blades because they were replaced when dulling first became apparent. It might be of interest to know that three men were engaged in this rip operation and with the steel blades a stop was made every 15 minutes for blade change. Think for a moment of the production hours lost when the machine was stopped every fifteen minutes and the three men idle, the sharpening charges consumed, and the faulty snaky cuts made as the steel blade dulled. The volume in dollars and cents in this instance is staggering.

Carbide Trim Saws

The advantages of a carbide tipped saw can be seen quite easily by anyone engaged in making veneered panels or using veneered panels in cabinet work. Ordinarily a salesman must not only sell the front office on carbide tipped tools, but usually must sell also the saw filer or tool room man. Recently a superintendent phoned long distance to ask that a carbide saw salesman call on him the following day. This request was rather strange as the salesman had been calling steadily for months but to no avail. It developed that this particular shop had suddenly become extremely busy, working 100 hours per week making plywood panels for the television cabinet trade.

Due to the hours of production, the steel saws used for trimming the panels to size were becoming dull very quickly. The cuts were rough and chipping was excessive. Often blades had to be removed immediately after being placed on the sizer because of excessive chipping and splintering. As a consequence, each shift was depositing many saws at the feet of the saw filers who had not only the rip saws to file and sharpen, but also the various planer, jointer knives, the trim blades, and all other cutting tools. It was just too much for them. When the salesman talked to the filer in this department, saw blades were actually stacked several feet high awaiting to be filed. It was these men who finally convinced the front office of the need for carbide tipped saws.

This organization is now using carbide rip blades on several saws and carbide trim blades on all their panel sizers. Results are outstanding. As mentioned, the shop is going 100 hours a week. The carbide trim blades go eight to nine weeks before the first sign of chipping on oak or Sonora veneer appears. These woods, as you know, are notorious for chipping. The average life between grinds, on other woods, is ten to twelve weeks. This shop now has approximately $7,000 worth of carbide tipped tools. The front office, the saw filers, production engineers, the customers, and of course the saw salesman are all pleased. The quality of the panels is better because of straighter cuts and elimination of chipping.

Some Advantages of Carbides

Carbides permit better finishes, have a greater life between sharpenings, and actually do some operations not possible with steel tools. The elimination of subsequent jointings, sandings, handling, etc. makes for great savings annually, to say nothing of higher production rates by steadily operating ma-

chines, possible by the elimination of down time resulting in the steady flow of products.

Carbide can be used successfully on 99 percent of all cutting operations. However, the writer does not know of a single plant so equipped. Some shops are eager, but many have tried a tool of this or that type and were not pleased with the results. There must be, and are, good reasons for their dissatisfaction. Let us go deeper into the subject to see if they can be overcome.

We are in a period more or less of reformation. It hasn't been too long since our machinery became motorized. One still sees spindles, originally belt-driven, now converted by motor to a self-contained unit. However, the majority of machines are fairly new. Both types should be equipped with carbide tools. This is difficult due to the old machines, but in the interest of progress, it should be done. In this transition period which actually never ends, competition forces constant changes.

Personal Observations

From his experience, obtained from calling on woodworking shops from coast to coast, and from the Lakes to the Gulf, the writer has arrived at some definite conclusions. The first essential to progress would be an open mind. An open mind to thoughts expressed by those engaged in the industry. This we could probably call education. Education is greatly needed by machine tool builders, tool makers and fabricating plants. Often it is so difficult to put an idea across. If you have ever gone to the Boss with a new idea you'll know exactly what I mean.

It seems then that this job of educating woodworking shops to the use of carbides must come from the machine tool builders and the cutting tool manufacturers. It is doubtful if the fabricating plant will go to them for new thoughts. However, before one can teach, he must know his subject well. Let us take up the woodworking machine tool builder and see how he fits into the picture.

Woodworking Machine Tool Manufacturers

There are, of all the woodworking machine tool manufacturers, only a handful who stand head and shoulders above the rest. Their reputation is due to their constant efforts to build superior machinery. They can well be called progressive. However, in many other cases the machinery builder is making the same machines today, keeping the same dimensional tolerances, using the same materials, and employing the methods of production as he did in the 20's. This manufacturer has no research department, probably has no engineer—for with his product he needs none, and probably no detail or assembly drawings. His employees have been making this same machine for such a long time without any improvement or change, that they know the dimensions by heart. If a part doesn't fit, then the assembler just makes it fit.

This criticism may seem harsh. It is no doubt, but progress cannot be made without just criticism or without the pressure of competition. These manufacturers must clean house and open their minds. They must build the finest machines possible, they must place their ingenuity to work making the finest quality castings, which are heavy, rugged, and machined to thousandths of an inch and not to fractional dimensions. The metal machine tool builders were confronted with the same situation. They faced the challenge and conquered it by newly designed, more rugged, and heavier machine tools. All this just for the use of carbides which offered more and better production. Where formerly a casting had two internal ribs, there are now five. Ways are planed, ground, spotted and then flame hardened. Some even have ways of hardened alloy inserts. Lubrication to all parts is now pressurized. Bearings, whether ball, taper, or roller, are all matched precision bearings. The finished tool costs more than formerly but this machine is capable of precision work and more of it, than previous models.

Many woodworking shops would like to use carbides and have actually tried them, but results were not to their liking, often due to poorly designed or poorly constructed machines. In these instances it is usually customary for the tool salesman to try several saw blades, or cutters in his efforts to make carbides work. Many times on new machines, which for some reason will not take carbide, a salesman, or salesmen from several competing companies will try many blades before one will produce a glue joint. Recently in a plant in North Carolina, a superintendent stated that four saw companies had sent men and blades in for use on his new rip saw. These four men tried 10 blades before one was found to produce a glue joint. Yet these 10 blades all produced good results on other machines. It was finally agreed that this particular machine had a specific vibration, and only after a blade of the same temperament had been found, did it operate as it should. Attention should be given to vibration dampeners as most metal machine tools now have.

Flanges

Flanges, arbor assemblies, and arbor bearings offer another touchy problem that should, and some day will be properly controlled. Many flanges and arbors on machines in the field have been checked with machinist's indicators. Runout is sometimes pitiful, while play of thrust bearings is exorbitant. Both flanges of an arbor should have not more than .001 runout, less would be better. I have faced many flanges in the field to less than .001 and have succeeded in making carbide blades perform successfully. The arbor flange should always be ground while in position on the arbor. Generally this is not done, as the flange is only turned and then placed on the arbor with no further attention. I know that these points have been brought up many times before, but there are still those who believe there is

no good reason to build precision into a saw as the stock will usually be jointed anyway. These fellows with their "good enough" ideas some day will see the light of Progress.

Jointed Swedge Tooth Blades

Have you ever wondered why a jointed swedge tooth blade produced smooth sawed surfaces and a good carbide blade could not on the same saw? The operator, when jointing the blade in position on the arbor actually grinds off the sides of the teeth to make them track exactly. This reduces teeth to correct width and also corrects for any flange runout on that particular machine. He then has a good blade for that machine, but it dulls quickly because he has ground off his clearances. Further, that blade cannot be put on any other machine and be expected to produce good glue joints. It has been prepared for one machine and no other. A carbide tipped blade could not be put on such a machine and be expected to produce good work because the flange runout would produce such a high tooth condition on the work as to render the work unusable without further operations. Carbide blades cannot be successfully jointed in position. For smooth finishes they must be put on machines in top condition. Machine tool builders should also give serious thought and research to building machines with variable rpm. Some day we will be machining each species of wood much as we machine different types of metal. This is accomplished by variable speeds and feeds.

The points brought out above are responsibilities of the machine tool builders. For the most part they are doing a grand job, but some still close their thoughts to perfecting their machines to take carbides. Some manufacturers are still resisting this progressive movement and openly advise they do not recommend carbides and want no part of them. We could not call these manufacturers open minded.

Responsibility of the Cutting Tool Manufacturers

The finger of criticism next points to the cutting tool manufacturer. He, too, is charged with a grave responsibility, and should be made to do penance for a long time for his methods in introducing carbides to the fabricators. In many cases carbides were over-sold to the customer. He was told that carbides would last forever and that his troubles would vanish. They were represented as a cure-all. In other cases the carbide tool salesman was an order taker and had no knowledge of the product. By quick talking he had permission to write an order. When the tool arrived, it was placed in production without one word of advice or caution. The result usually was a badly chipped tool, damaged in placing it on the machine. The cuts were faulty due to lack of proper rpm. or to foreign material between tool and flange, or to sloppy fits. If a tool did perform satisfactorily, it was allowed to run too long, causing excessive wear to tips and necessitating a large repair bill. When a tool failed to work successfully, the customer registered a complaint. This, in most cases, was ignored by the tool manufacturer. He flatly stated that the tool was in good condition when it left his shop, and if it didn't work properly, it was certainly the fault of the operator. This produced bad feelings, as the customer had purchased a tool in good faith and it had failed to give him the desired results. He either wanted a refund or satisfaction, but got neither, and consequently developed the feeling that all manufacturers were out to get him.

High Cost of Carbides

The cost of carbide tools is another stumbling block. Plants are not eager to spend hundreds of their scant dollars for a possible money saver.

Recommendations for Tool Manufacturers

The cutting tool manufacturer should only offer thoroughly tried and tested tools for sale, and then only for use by skilled personnel on machines in good condition. His salesmen should be thoroughly trained in the subject so they can be of real service to the woodworkers should trouble develop, and offer constructive advice. The salesman and the tool manufacturer should be truthful and they should refrain from buck passing. Tool manufacturers should develop newly designed tools. In many cases the same tools used in the old days are tipped with carbide, but carbides demand specially engineered cutter bodies. Justifiable complaints should be quickly and pleasantly handled for mutual good feeling. And lastly, the tool maker must seek ways to lower his costs so that carbide tipped tools can be available to every shop for every operation. Carbide costs are high and in many cases out of reach. A reduction in price, with quality maintained, would permit widespread use and real progress would be made. It would also force machine tool manufacturers to build machines capable of carbide usage.

The Fabricating Shop

The last, but most important of the three interested groups is the wood fabricator. Many are really progressive, but the majority go along from day to day in the same manner as they did years ago. These fellows need education. Their minds are closed. They are reluctant to take advice or to make changes that cost money. Usually the initial outlay is all they consider. This barrier to progress is gradually being diminished, as sons of owners are now coming from the universities where they have seen the advantages of modernization, and usually won't rest until changes are made in their plants. Many shops are sending key men to educational meetings where new methods are discussed. This helps progress as it creates a desire in the minds of these key men who will try to duplicate these improvements.

Any and all progress costs money. He who profits most should pay the most. Often, tool or machinery builders are asked to design or even build a special item at considerable expense. The customer will approach them with the proposition that if it works he will buy. This is too much to ask. The fabricator must be willing to spend his own money for improvement. This is so much in contrast to the ways of the metal workers. They, when a new idea or method is brought up, commission someone to build it. They realize, from experience, that it cannot be had any other way.

Most woodworkers do not employ engineers. This position is usually filled by the tool and machine manufacturer. This spirit of helpfulness is granted willingly, but it has its bad points, especially in the matter of designing cutters for a given pattern or shape. The knife and cutter head people will tell you of the number of re-works on a no-charge basis they make in a year. This could be eliminated if all data were incorporated in blueprints, but in the woodworking industry most tools have not been made to prints, but to shapes and designs. With this method trouble develops.

Maintenance of Machinery and Tools

Education in machine and tool maintenance is also vitally important. There may be many, but to my knowledge, there are only a few shops employing full time maintenance crews. It is their duty to check every checkable point, and repair every machine every thirty days. Not only does this eliminate costly repairs and down time, but it also keeps a machine in proper condition for carbide or other application. Machine tools must be in good order for carbide use. Good order means proper rpm., true running arbors and flanges, correctly operating feed chains, end play in spindles down to a minimum, and all working parts closely fitted and properly lubricated.

The woodworker should also charge someone with the responsibility of frequent attention to his carbide-tipped tools. He should handle the tools with extreme care when putting on the machine. He should know that bumps, nicks or other foreign material between tools and collars make for an inaccurate assembly with resultant poor finishes. He should know when to remove a tool for sharpening. The fact that a tool is still producing satisfactorily is no proof that it is not dull. More tools are prematurely worn out by over running than by any other means. A predetermined grinding date should be established fo every tool. This permits the potential life built into the tool to be used. Ordinarily a tool is so badly used from long operation after initial dulling that much carbide is wasted when ground. Often it is necessary to remove as much carbide in grinding out nicks as would ordinarily be removed in four or five or more normal regrinds.

Enough for the criticism. Things have been said that might have hurt. They were not meant to hurt, however, but rather were offered for the good of the industry. You will note that remarks of critical nature were not directed to any one group, but rather to the three groups controlling progress. The remarks were made in a spirit of friendliness and totally without malice and the writer sincerely hopes that they will be taken in the same spirit in which they were given.

The writer and his associates have a house to clean and, believe me, we're cleaning now and are going to clean until our house is in perfect order. Progress can only be made at an expense in one form or another. You would undoubtedly prefer to make progress voluntarily rather than to be forced into a change by competition. It costs no more to progress with carbides than with other means, and from past personal experiences in the metal trades and in the woodworking industry, more profits can come from carbides than from any other single item.

TECHNICAL SESSION V—Wed., May 9, 1951, 10:30 A. M.

General Subject: Wood Preservatives and Treatment Related to Defense

Co-Sponsor: American Wood-Preservers' Association

Chairman: Ralph Bescher—**Recorder:** Robert A. Zabel

The Production and Use of Fire Retardant Treated Lumber

H. W. ANGELL, *Wood Technologist, American Lumber & Treating Company, Chicago, Illinois*

The pressure treating of lumber to increase its fire resistance, which began in the United States in the 1890's, greatly expanded during World War II. Aside from the stimulus brought by war, peace time fireproofing is expected to expand because of the development of suitable large-scale fire tests and their acceptance by building officials and building code committees as criteria for the acceptance of building materials for use in given locations. Service records for fire retardant lumber are gradually accumulating. It may not be long before the insurance underwriters will seriously review the entire field of fireproofed lumber with respect to reduced insurance rates.

THE term "fire retardant treated lumber" refers to wood which has been impregnated with chemicals to increase its fire resistance. The chemicals are forced into the wood under pressure in water solutions, after which the material is either air-dried or kiln-dried leaving the dry chemical deposited in the wood.

In the United States the fireproofing of wood, as it is sometimes called, was started by the Protexol Corporation in the early 1890's, with the first commercial installation reportedly made in 1895 (*17*). From that time up until the beginning of World War II the industry was more or less localized around the New York-New Jersey area. However, the tremendous military demands for fire retardant treated lumber in the early 1940's caused the industry to become nationwide. Today, there are more than 30 wood preserving plants in the United States equipped to produce pressure treated fire retardant lumber. Whereas the production during World War II was much greater than in the succeeding years of peace, it is significant to note that there is still a sizeable demand. Table 1 gives the production in board feet of lumber treated in the years 1947, 1948, and 1949 (*22*). Also shown are the quantities of dry fire retardant chemicals used.

TABLE 1.—QUANTITIES OF TIMBER FIREPROOFED, AND QUANTITIES OF FIRE RETARDANTS USED IN THE UNITED STATES 1947–1949

Region	Timber Treated (board feet) 1947	1948	1949
Atlantic Coast	3,218,545	6,042,391	5,621,829
Southern Coast	315,797	1,188,102	600,987
Interior Eastern	1,252,968	965,036	1,192,922
Interior Western		750,185	259,171
Pacific Coast	237,583	634,073	363,728
Total	5,024,893	9,579,787	8,038,637
	Fire retardants used (pounds) 1947	1948	1949
Total	1,136,291	1,582,437	1,348,757

The production in the 1950's will no doubt greatly exceed the figures shown in the table because (1) military demands are expected to increase, (2) recognized fire testing agencies have now tested and rated all commercial fire retardants in accordance with approved fire test procedures, and (3) the building code committees have set up requirements for various forms of building construction based on the ratings derived from these fire tests.

Table 2 gives the commercial fire retardants and their formulations (*5 10 11*). Lumber and timber furnished under the Navy Department specifications are accepted either on the basis of absorption and penetration requirements only or on the basis of small scale fire check tests. There are two alternate test methods known as the crib and fire tube tests, both of which are standard A.S.T.M. methods (*1 2 3*).

The American Wood Preservers' Association (*5*) is currently adopting four formulations as standard A.W.P.A. fire retardants (See Table 2). Specification numbers for these four retardants, as well as specifications for treatment and acceptance, are expected to be determined in the near future.

Fire Tests and Ratings

To properly evaluate fire retardant treated wood in the laboratory, the test must be on a reasonably large scale, and the exposure of the test specimens to the fire must be comparable to the conditions encountered in actual fires. Built-up structures such as doors, floors, and partitions are generally tested for resistance against fire penetration, and the results are based on the period of time that the unit will resist the penetration of a standard test flame. Doors containing fire retardant wood have been tested and rated by Underwriters' Laboratories, Inc. and hence are commercially available bearing the Underwriters' label.

Miscellaneous building materials of varying thicknesses and compositions are tested differently. One of the more important procedures is the Standard Test Method for Fire Hazard Classification of Building Materials (*12 23*) developed by Underwriters' Laboratories, Inc. This test requires a specimen 20 inches wide by 25 feet long and measures the flame spread along the surface of the material, the fuel

TABLE 2.—FIRE RETARDANT FORMULATIONS

Fire Retardant	Specifications: Navy Department	Specifications: American Wood Preservers' Ass'n	Formulation	Percent
Ammonium Sulphate-Phosphate	51C38 Type I	———	Ammonium sulphate, $(NH_4)_2SO_4$	78.0
			Ammonium phosphate, $(NH_4)H_2PO_4$ or Diammonium phosphate, $(NH_4)_2HPO_4$	19.0
			Sodium dichromate, $Na_2Cr_2O_7.2H_2O$	3.0
Borax-Boric Acid	51C38 Type III	———	Sodium tetraborate, $Na_2B_4O_7$	60.0
			Boric acid, H_3BO_3	40.0
Chromated Zinc Chloride Preservative (Fire Retardant Absorption)—CZC	51C38 Type IV	Number to be assigned	Zinc chloride, $ZnCl_2$ min.	77.5
			Sodium dichromate, $Na_2Cr_2O_7.2H_2O$ min.	17.5
Chromated Zinc Chloride (Fire Retardant)—CZC(FR)	——	Number to be assigned	Chromated Zinc Chloride[1]	80.0
			Ammonium sulphate, $(NH_4)_2SO_4$	10.0
			Boric acid, H_3BO_3	10.0
Minalith	51C38 Type II	Number to be assigned	Ammonium sulphate, $(NH_4)_2SO_4$	60.0
			Diammonium phosphate, $(NH_4)_2HPO_4$	10.0
			Sodium tetraborate, $Na_2B_4O_7$	10.0
			Boric acid, H_3BO_3	20.0
Protexol Class A	——	———	Not disclosed	
Protexol Class B	——	———	Not disclosed	
Protexol Class C	——	———	Not disclosed	
Protexol Class D—Pyresote	——	Number to be assigned	Zinc chloride, $ZnCl_2$	35.0
			Ammonium sulphate, $(NH_4)_2SO_4$	35.0
			Boric acid, H_3BO_3	25.0
			Sodium dichromate, $Na_2Cr_2O_7.2H_2O$	5.0
Zinc Chloride	51C38 Type IV	———	Zinc chloride, $ZnCl_2$	100.0

Note: Undisclosed formulations accepted by Navy Department if treated wood passes fire test requirements as set forth in Navy Department Specification 51C40.

[1]Same as Chromated Zinc Chloride Preservative formula given above.

contributed, and the noxious fumes liberated, if any. A numerical rating is assigned to each material tested based on 0 for asbestos cement board (incombustible) and 100 for untreated red oak (combustible).

Results are available for various species of lumber and plywood treated with commerical fire retardants. Table 3 lists the various retardants and results as currently being reported to the American Wood Preservers' Association.

TABLE 3.—RESULTS OF FIRE HAZARD CLASSIFICATION TESTS

Fire Retardant	Species and Type of Wood	Results for Material Treated Throughout Its Cross-Section Except as Indicated in Footnote: Flame Spread	Fuel Contributed	Smoke Developed
Chromated Zinc Chloride (Fire Retardant Absorption)—CZC				
1 Lb. Per Cu. Ft.	Southern pine lumber	70	60	Less than untreated
2 Lb. Per Cu. Ft.	Southern pine lumber	45	40	Less than untreated
3 Lb. Per Cu. Ft.	Southern pine lumber	35	30	Less than untreated
4 Lb. Per Cu. Ft.	Southern pine lumber	30	25	Less than untreated
1 Lb. Per Cu. Ft.	Douglas fir lumber	55	40	Less than untreated
2 Lb. Per Cu. Ft.	Douglas fir lumber	40	30	Less than untreated
3 Lb. Per Cu. Ft.	Douglas fir lumber	35	30	Less than untreated
4 Lb. Per Cu. Ft.	Douglas fir lumber	30	25	Less than untreated
Minalith				
Type M (Moderate)	Southern pine lumber	40	30	Less than untreated
Type H (High)	Southern pine lumber	30	25	Less than untreated
Type M (Moderate)	Douglas fir lumber[1]	40	15	Less than untreated
Type H (High)	Douglas fir lumber[1]	30	5	Less than untreated
Type M (Moderate)	Douglas fir plywood	50.60	30–35	Less than untreated
Type H (High)	Douglas fir plywood	40–45	20–25	Less than untreated
Protexol				
Class A	Red oak and Douglas fir lumber, and Douglas fir plywood	25–35	15–20	Less than untreated
Class A	Maple, birch, yellow pine, and ponderosa pine lumber	40–50	20–25	Less than untreated
Class D—Pyresote	Yellow pine lumber	25	10	25–30
Class D—Pyresote	Northern pine lumber	20	5–10	20–75
Class D—Pyrostoe	Cottonwood lumber	25	0–15	20–40
Class D—Pyrosote	Red oak lumber	35–50	20–25	25–45
Class D—Pyresote	Douglas fir lumber	20–30	10–15	30–60
Class D—Pyresote	Douglas fir plywood	25–30	10	Negligible

[1]Results based on lumber treated to a minimum penetration of ⅜ inch.

Fig. 1.—Twenty increment borings are taken from each charge. Eighteen of the twenty borings must pass the minimum penetration requirements.

Building Codes

Building officials and code committees have made rapid strides in the past five years with respect to adopting flame spread limitations for building materials to be used in various parts of buildings. The Underwriters' classification test has proved to be a good yardstick since it lends itself to the purpose of arriving at several degrees of flame spread resistance. Thus, modern codes may provide for four and sometimes five degrees of fire resistance, the particular degree required depending on the type of building and the location of the material inside the building.

The Basic Building Code, as written by the Building Officials Conference of America, Inc., provides for four classes of fire resistance for building materials as follows: (1) incombustible, (2) fire retardant, (3) slow burning, and (4) combustible. In highly important places incombustible materials are required, and where the fire hazard is deemed as less important, fire retardant, slow burning, or even combustible materials are permitted.

The City of Cleveland Code has adopted five classes of fire resistance which have also been tentatively adopted by the Pacific Coast Building Officials Conference in their Uniform Building Code.

The Municipal Code of Chicago has four degrees of fire resistance known as Classes I, II, III, and IV.

Table 4 gives the flame spread ratings required by each of the four codes cited for the various classes of fire resistance that have been adopted.

A test method which is sometimes accepted as an alternate to the Fire Hazard Classification Test is the Prefabricated Acoustical-Unit Test (*6*) described in Federal Specification SS-A-118a. The test specimen resembles the top of a card table with the test flame being applied from underneath. The results, which are based on the extent of flaming and glowing, indicate that the material is either incombustible, fire retardant, slow burning, or combustible. While this test method is on a much smaller scale and does not lend itself to the numerical rating system, the test apparatus is more available than the larger apparatus developed by Underwriters' Laboratories, Inc.

TABLE 4.—FIRE HAZARD CLASSIFICATION RATINGS REQUIRED BY BUILDING CODES

Building Code	Where Building Material Is Required To Be—	Flame Spread Rating Must Be—
BOCA Basic Building Code	Incombustible	0– 25
	Fire Retardant	26– 50
	Slow Burning	51– 75
	Combustible	76–100
City of Cleveland Code and PCBOC Uniform Building Code	Incombustible	0– 15
	Fire Retardant	16– 30
	Slow Burning	31– 75
	Combustible	75–200
	Highly Combustible	Over 200
Municipal Code of Chicago	Class I	0– 15
	Class II	16– 30
	Class III	31– 60
	Class IV	61–160

Uses for Fire Retardant Treated Wood

The major use for fire retardant lumber is, of course, for building construction which includes trusses, sheathing, decking, stairways, subflooring, finish flooring, paneling, furring, insulation and duct work, trim, doors, lining, sash, etc. Examples of types of buildings are office buildings, hotels, factories, hangars, hospitals, ordnance plants, supply depots, round houses, garages, oil refineries, terminal wharf sheds, warehouses, barns, and private homes (*14 16 17 21*). In shipbuilding and main-

Fig. 2.—Fire retardant mahogany plywood paneling complies with local building code requirements.

tenance, fireproofed wood is used for damage control shoring, bulkheads, interior floors, paneling, partitions, interior walkways, decking, grating, and hatch covers (*18*). Miscellaneous uses include scaffolding, poles, bracing, guard rails, circus seats, etc. (*17*).

Fire retardant plywood for non-military purposes is used mostly for interior paneling in office buildings, hotels, cocktail lounges, etc. The armed forces have used a considerable amount of fireproofed plywood for undisclosed overseas construction. All plywood, including fire retardant plywood, for military purposes is procured in accordance with Military Specification MIL-P-66A, Plywood; Flat Panel (*9*). Fire retardant plywood is required to pass a modified Prefabricated Acoustical-Unit Test as described in the Military Specification.

Fire retardant lumber and plywood is best suited for use in sheltered locations where little, if any, leaching action can take place. When it is used in exposed places, as for catwalks, stairways, etc., or for exterior wall or door paneling, it should be protected with a moisture resistant paint. Also protection against leaching action may be realized through the use of sealers, the application of which may be performed at the treating plant (*15*).

Decay and Insect Resistance

The amount of chemical required to fireproof a cubic foot of wood varies from about 2 to 12 times the amount required for preserving the same amount

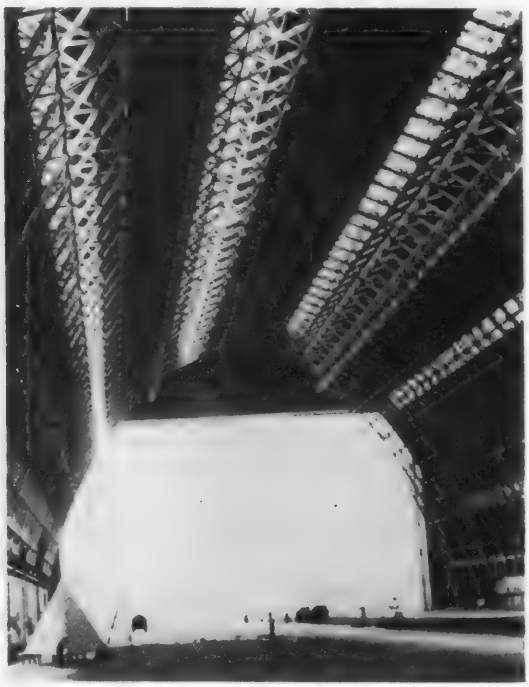

Fig. 3.—Blimp hangar with fifty-three catenary arches of fire retardant lumber. (U. S. Navy photo)

Fig. 4.—Warehouse with treated plywood sheathing under composition roof to reduce fire hazard.

of wood against decay and insects, depending on the degree of fire resistance desired. Because the chemicals used in fireproofing are also toxic to fungi and insects, the user realizes the advantages of preservation as well as fireproofing, and the degree of preservation almost always exceeds the protection offered by standard salt type preservative treatment. Of course this high degree of preservation becomes superfluous where the wood is used in places where a decay hazard does not exist. On the other hand, it is highly desirable where decay hazards do exist as in certain factory roofs, round houses, and in exposed or semi-exposed structures.

Zinc Chloride and Chromated Zinc Chloride are standard preservatives in all technical associations concerned with wood preservation as well as to the Federal Government. Thus, their value as preservatives is accepted without qualification.

The chemicals borax and boric acid are not ingredients in standard preservatives but laboratory tests have shown them to be comparable to zinc chloride with respect to toxicity as such. Also a certain amount of stake garden test work has confirmed the laboratory findings. Although actual service records are not available, the toxicity of borax and boric acid has led to their acceptance as both fire retarding and decay resistant. Some published results of petri-dish toxicity tests are as follows:

Chemical	Concentration of Chemical in Agar Necessary to Kill the Fungus Madison No. 517	Reference
Borax	0.13	13
Boric Acid	0.25	13
Sodium Dichromate	0.03	13
Zinc Chloride	0.35	19

The variation in killing concentration figures will not necessarily reflect performance in actual service because of other factors that enter the picture. The figures simply indicate that the chemicals possess toxicity.

The value of ammonium sulphate and ammonium phosphate for decay resistance has been questioned

in the past, but some relatively recent laboratory tests (*20*) have shown that 2 lb., 4 lb., and 6 lb. retentions per cubic foot of wood of these chemicals possess high initial resistance to decay. Furthermore, after a period of exposure a fair degree of resistance still remained.

Fire Insurance

The primary purpose of fireproofing is, of course, to increase the fire resistance of the wood and thereby permit its use where untreated wood is considered hazardous to life or property or both. The next question is whether or not the insurance underwriters will allow reduced rates where fire retardant lumber is used.

There are a few cases on record where the insurance people have recognized fire retardant lumber but, by and large, there has not been general acceptance in this respect. The reason is that the insurance underwriters are waiting for more experience, and rightfully so. There is no substitute for service records. Furthermore, claims for the worth of a product cannot be based on a few scattered experiences; acceptance must be based on a reasonably large number of authenticated records. Unfortunately, one must be content to wait for experience in the case of fireproofed lumber. The mere passage of time is all that is required to prove or disprove the worth of a wood preservative against decay. Fires are not as prolific as decay fungi and insects which accounts for the difference. Still, the service data accumulated by all the producers of fireproofed wood taken as a group is quite impressive. It is entirely possible that before very long the insurance people will review the entire field of fireproofing with the thought of reduced insurance rates. The following records are presented as the beginning of a comprehensive compilation of case histories.

Fig. 5.—More than 100,000 board feet of fireproofed southern pine joists, rafters, braces, and furring strips were used in this hospital as a safety measure.

Service Records

Case No. 1 (Reference 17)—A serious explosion and powder fire at one of our larger ordnance plants, causing what appeared to be the destruction of a fire retardant-timber building, actually resulted in the loss of the building for only a short period. Construction was such that the walls blew outward from the top. Their footings were firmly anchored, allowing great flexibility. The roof was constructed in similar sectional fashion. The fire had the effect only of charring the exterior surface of the inside. After the fire the walls were lifted back into place and refastened under the eaves. The roof sections were re-installed. The minor char was disregarded and the building was ready for occupancy.

Case No. 2 (Reference 17)—A very serious oil fire ignited the contents of several floors of a fireproof building. The intense heat caused the buckling and warping of more than 25 metal-clad doors which had to be replaced. The flames passed at least two of these doors. The fire was stopped by a panel door made of fire resistant wood. The door was found to be still sound and was refinished and re-installed. During the progress of the fire, incidentally, the fire department was unable to get to any point where they could fight the fire and actually the fire burned itself out after consuming all the combustible contents in the area.

Case No. 3 (References 7 and 14)—An intense lacquer fire broke out in a section where products were sprayed with paint. The building had no automatic sprinklers. When the plant firemen arrived they first directed their hoses to the wood roof. Quickly discovering that the fire was not spreading there, they turned the water to the floor, where the lacquer was burning furiously. The fire was confined to an area about 20 by 50 feet, although wiring and lighting fixtures were melted in a ceiling area 20 feet by 100 feet. Untreated wood benches at floor level were consumed. Fire retardant wood in the ceiling was charred to a depth of about ¼ inch by the intense heat. Although metal fixtures and wiring had to be replaced, structural strength was retained, and no repairs to the wood were needed or made.

Case No. 4 (References 7 and 14)—An explosion in a magnesium foundry blew 130 pounds of magnesium from a crucible to a height of 12 feet. Some of it caught on the top surfaces of a fume hood, made of transite on a fire retardant wood framework. Although exposed for ten minutes to magnesium burning at approximately 4000° F., there was no evidence of any fire spreading or of charring beyond the area in direct contact with the molten metal. No replacement of treated wood due to fire damage was required. It is the opinion of the foreman of the department that the extent of damage would have been much greater if fire retardant wood had not been used. It is also believed that the intense heat would have ignited the roof had it not been constructed of fire retardant lumber.

Case No. 5 (Reference 8)—Fifty thousand feet of fire retardant lumber were exposed to a 3-hour fire in a lumber yard. A 120 by 80-foot building,

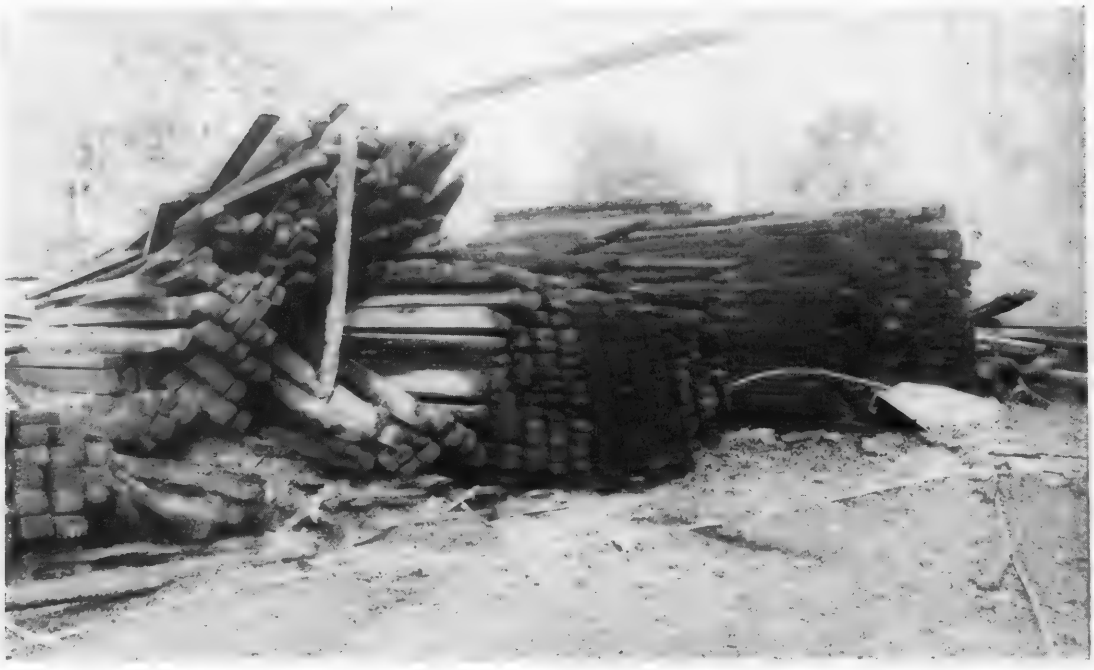

Fig. 6.—Service record for fire retardant wood. A three-hour fire virtually destroyed a lumber yard but only charred the edges of treated wood in storage.

three trucks, millwork, yard lumber, and a coal shed were destroyed before three companies of firemen put out the blaze. But with untreated lumber blazing on and around it (hot enough to break a fire-engine windshield fifty feet away) and five thousand pounds of lignin burning beside it, the fire retardant wood just charred. The center pieces in the piles were not affected.

Case No. 6 (Reference 4)—During a hurricane which struck one of the Navy's blimp patrol bases, three fire retardant wood hangars collapsed. Design and construction were well executed, and the structural failures were considered to be in the "act of God" classification because the hurricane wind forces were far in excess of those anticipated. The collapse was followed by very destructive fires. The fire retardant wood gave a good account of itself. Photographic evidence showed that combustion of treated members and aircraft was complete where large quantities of flammable liquids were present at the floor of the hangars. However, it was seen that large quantities of wrecked and splintered treated wood members, immediately outside the zone of burning flammable liquids, either resisted ignition or were only partially burned. Preliminary reports indicated that there were no burning brands from the fire. It was reported, and supported by photographic evidence, that the fire did not occur in large masses of debris of the hangar walls which fell to leeward and away from the hangar floors.

Case No. 7 (Reference 4)—A blimp containing 450 gal. of gasoline burned during re-fueling operations in a Navy hangar, which itself was undamaged. After the gasoline ignited, flames spread rapidly over the finish of the blimp car and the canvass-rubberized blimp bag. An area approximately 100 feet wide of fire retardant treated wood on the underside of the roof was exposed to flames rising over 150 feet. It is reported that the fire lasted nearly two hours. While the concrete floor spalled in the fire area and a metal conduit was destroyed, the treated wood did not support combustion or spread flame, and no structural damage occurred to the hangar. It is believed that untreated lumber would have ignited and that it would have been impossible to control a fire of this intensity.

Note:—Although they cannot be considered as authenticated records, it has been reported verbally that there were a number of fires on Naval vessels containing fire retardant wood. It was further reported that the treated wood effectively retarded the spread of flame. Accurate records were impossible because of continual personnel changes between ships and the lack of written reports immediately after the fires.

Permanence of Effectiveness

A second consideration with regard to service is whether or not the fire retardant retains its effectiveness over a long period of time. Fortunately, it

is possible to measure effectiveness by extracting material that has been in service for several years and subjecting it to a fire test. The Forest Products Laboratory found that wood which had been in service indoors for more than 40 years still possessed excellent fire retardant properties (*17*).

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Discussion

Ted C. Weill (Michigan State College): Does treatment with zinc chloride render wood fire-resistant?

Mr. Angell: Zinc chloride is considered a good fire retardant. For chromated zinc chloride the ratings given in the paper verify this as do service records.

George A. Garratt (Yale School of Forestry): Could you give us some idea of the present cost of fire-retardant treatments? In the late 20's this amounted to as much as $95 to $100 per thousand board feet, exclusive of the cost of the lumber, and in 1937 it was about $80 per thousand feet.

Mr. Angell: Prices vary from $40 to $50 per thousand board feet, depending on treatment.

Ralph H. Mann (American Wood-Preservers' Association): There are two basic categories which govern the cost of fire-retardant treated lumber. The first category is lumber treated for high fire retardance such as fire doors, interior trim, etc. Such treatments require complete penetration of the chemicals through the entire cross-section of the lumber. Net retentions of dry salt per cubic foot are high in this instance. Cost of such material, which will pass the New York City Building Code requirements, range from $120 to $175 per thousand feet, board measure, depending upon the species of wood treated. Such costs, of course, include the kiln drying of wood after treatment to a 10 percent moisture content.

The second category of fire-retardant treated wood is that of structural lumber where the criteria

are (1) prevention of initial ignition by fire; and (2) the decrease of flame spread over the surface of the timber member. Such treatments are not, of course, complete penetration treatments. They do provide, however, from ¼ inch to ½ inch penetration on all sawn surfaces. Tests of material treated in this second, or flame spread category are in accordance with the Tunnel Test of the Underwriters' Laboratories, Chicago, Illinois, which measures flame spread. Fire-retardant treated lumber of this category rates flame spread classifications of between 25 and 35 as compared with untreated red oak as 100. The cost of such treatment varies from $40 to $60 per thousand feet board measure which is based upon both species and net retention in pounds per cubic foot. No consideration of kiln drying is taken in this price estimate.

Subsequent to the disastrous circus tent fire in Hartford, Conn. some years ago, the fire insurance companies of the nation applied to the American Standards Association for the appointment of a committee to prepare an A.S.A. Standard for Places of Outdoor Assembly, Grandstands and Tents. The number of this standard is A.S.A. Z–20.3, dated 1949. As to their recognition in that standard of fire-retardant treated wood, I quote:

> "If the grandstand units are made of flame resistive wood treated in accordance with standard practice, the permitted areas and lengths may be doubled."

This reference is with regard to a statement regarding wood grandstands, meaning untreated wood grandstands. This statement quotes:

> "No wood grandstand unit shall exceed 10,000 square feet in ground area or 200 feet in length."

It is therefore evident that the Underwriters themselves have at last recognized fire-retardant treated wood.

Richard N. Hammond (Weyerhaeuser Timber Co.): Is ammonium sulfamate used in wood preservation?

Ralph H. Bescher (Koppers Co., Inc.): Sulfamate slowly converts to ammonium sulfate in wood, therefore there is no advantage in purchasing the higher priced chemical.

John H. Sweeney (Aetna Plywood & Veneer Co.): If fire-retardant treated plywood is used as wall paneling and is painted or varnished, what effect does this have on the flame spread classification?

Mr. Bescher: Some tests, made by adding finishes, indicate that the fire-retardant effect still is good—fire-retardant effect is due to the gasses which are produced from hot wood.

Mr. Angell: The Underwriters ratings, of course, apply to the product as is, without any surface coating. Whether surface coatings are permitted depends on the local code provisions. Committee A51 of the American Standards Association has a proposal in tentative form which states that coatings may be applied to fireproofed materials provided such coatings do not exceed 1/25 inch. This means that a 1/28 inch untreated veneer could be glued to fireproofed plywood.

Frank J. Kotroba (Michigan State College): What effect has the fire-retardant treatment on dimensional stability?

Mr. Angell: Concentrations so high (20 percent) get a beneficial chemical seasoning effect.

C. F. Paul (Fox Bros. Manufacturing Co.): Full-cell chemical impregnation of wood with fire-retardant chemicals or a combination of preservative and fire-retardant chemicals reduces the porosity of the wood to an extent that greatly reduces the moisture absorption, and as a result, an increased degree of dimensional stability is obtained over untreated wood. We have run many tests on the volumetric moisture absorption, and the resultant dimensional increase of both untreated and pressure-treated woods, and there is a pronounced reduction in the absorption and the fiber distortion in the treated samples over the untreated.

Fred J. Meyer (Dow Chemical Company): Does the use of water as a carrier of fire-retardant, and subsequent drying, cause serious problems in regard to degrading of lumber?

Mr. Angell: No. After the wood has been treated it is dried with care so as to prevent warping, checking, etc.

Mr. Paul: Wood, having a natural affinity for water, readily absorbs fire-retardant and preservative chemicals soluble in water, and under proper processing methods and conditioning of lumber in advance of the chemical impregnation, does not in any way disturb the wood fibers, and in my opinion, does not reduce the stress value except to reduce its compressibility due to the reduced porosity of the wood. The most important processing after chemical impregnation is in the evaporation of the water through proper methods of kiln drying. Chemically impregnated lumber cannot be successfully kiln dried or cured on untreated lumber schedules. Proper procedures and kiln drying to moisture contents of 5 percent to 7 percent will obtain excellent stabilization of both wood fiber and chemicals.

C. R. Silversides (Abinbi Power & Paper Co., Ltd.): Do any producers of fiber wallboard or hardboard add fire-retardant chemicals in the forming process to fireproof their finished wallboard?

Mr. Angell: Several firms have done a lot of testing along those lines. I believe some of them do incorporate fire-retarding chemicals in wallboard.

Mr. Paul: Celotex and other fiberboard manufacturers, especially on fiberboard Acousti-Tile, offer, at an additional cost, a surface coating of primer paint which they claim has fire-retardant properties. Chemical impregnation of fiberboard is not practical due to the heavy absorption of chemical with the resultant reduction in insulation or sound-absorbant values.

Wood Preservatives in the National Emergency

GEORGE M. HUNT, *Forest Products Laboratory,*[1] *Forest Service, U. S. Department of Agriculture*

Emergency conditions may necessitate the use of second- and third-choice preservatives but an understanding of all factors involved can operate to avoid costly mistakes and provide the best alternate treatment.

Introduction

NATIONAL mobilization for defense brings about shortages of materials, reduces our freedom to purchase and use what we please, and generally upsets our normal practices. Limited quantities, reduction in quality, hoarding, gray markets, black markets, rationing, and numerous other irritations and obstacles beset the path of the man who wants to do the best possible job at the most reasonable cost. In wood preservation as well as in many other operations, shortages of preferred materials may force widespread use of second- or third-choice materials. The problem then is to make the best possible compromise and do the best job the conditions will permit.

I will not undertake to predict whether our supplies of standard specification oil or salt preservatives will be adequate, but we all know that during World War I and World War II we could not have all the preservatives we wanted of the kinds we wanted. Experience indicates that we will face the same situation again as soon as allocations and rationing become the order of the day. What can be done about it with a minimum sacrifice of the quality of the treated wood?

Choice No Longer Limited

Fortunately, each succeeding "emergency" finds us with a greater variety of preservatives that can be used with confidence and a greater volume of laboratory and field tests and service records to draw upon. Furthermore, in a time of preservative shortage we can and often must take longer chances with a relatively new preservative than we might care to take when we have free choice. We can be less insistent, for example, that a preservative have 25 years of favorable service records before it may be used. Nevertheless, we cannot afford to throw caution to the winds and accept anything new that some promoter recommends. Serious and costly mistakes have been made in that way.

Preservative Not Sole Factor

The preservative, of course, is not the only factor to be considered. Methods of application, retentions, and penetrations are also of importance, and specification requirements may have to be altered from time to time if circumstances make it impossible to carry out the original requirements. Easing of specification requirements must not be left to the whims of inspectors, contractors, or uninformed purchasing officers. Every such reduction is likely to sacrifice quality, and that should be done only by competent authority in position to weigh the risks and compare the alternatives that may be possible. A mistake in judgment can have serious consequences that may not show up until some years later. Instances are on record in which the reputation of treated wood in general has suffered severely because poorly treated material was accepted under war-time conditions and used in important structures under the assumption that it was properly treated. Its inevitable early failure caused an unwarranted loss of confidence in the value of well-treated wood. In other instances, early failure and great loss resulted from using an unorthodox method of protecting marine piling merely on the basis of the promoter's claims, when standard specification treatment was still available.

The extent to which specification requirements may be relaxed and chances taken should be governed in large measure by the importance of the product or structure and the cost of maintaining or replacing it in case of early failure. Fence posts, small poles, and moderate-sized temporary structures of all kinds are relatively low in cost and easy to repair or replace, in comparison with large telephone and transmission line poles, large bridges, wharves, heavily used railway tracks, and the like. The need for maximum protection increases with the importance and cost of the structure and the difficulties of repairing it without serious interruption in service. Similarly, piles in salt water need better protection than land piles, and wood in warm, humid climates needs better protection than that in cold or dry climates. No set of emergency rules or regulations can make adequate and fair distinction between the more important and the less important but, in time of national emergency and severe preservative shortages, every practical effort should be made to see that the best preservatives are reserved for the structures most in need of them.

[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

In stretching our preservative supply to make it go as far as possible, we may frequently have to dilute coal-tar creosote with other oils to a much greater extent than is desirable and to accept oils that are not quite up to normal specification requirements. With both oil- and water-borne preservatives it may be necessary to reduce the permissible retentions. In no case, however, should it be necessary to accept poor treatment or timber that has begun to decay before it is treated. Poor workmanship, slipshod methods, poor inspection, and downright chiseling are never justifiable; they cannot be countenanced when we are at war or preparing for it.

Many Preservatives May Be Scarce

The availability of different preservatives is likely to vary widely in different parts of the country and with changing economic conditions. If creosote importation is seriously reduced, as it was in World War II, our domestic producers will be unable to meet all demands upon them. If the amounts of copper and chromium salts available for wood preserving are seriously curtailed, which may easily happen, we will not have enough of such good preservatives as Celcure, Chemonite, chromated zinc chloride, copper naphthenate, Erdalith, Greensalt, Osmose, and Tanalith.

Newer preservatives such as Boliden salts will not be much help because they, too, usually need chromium or other critical metals. Even our old stand-by, zinc chloride, could become seriously restricted. As long as it remains available in adequate supply, however, zinc chloride can serve as an exceedingly useful substitute for less readily leachable preservatives that may be unavailable. We know now better than we did during the days of World War I that retentions of one-half pound of zinc chloride per cubic foot, in common use then, are too low. It would have a better reputation now than it has if the retentions used in those days had been doubled.

Chlorinated phenols, of course, to the extent that they may be available, will help out greatly in the event of a creosote shortage, as they did in World War II. Although they are not effective against marine borers, they can be counted on for good protection of wood in land or fresh-water use. The limits on the quantities of pentachlorophenol that may be produced are the amounts of chlorine and phenol that may be spared for the purpose.

I will not attempt to catalogue the possible substitutes for the standard oils and water-borne preservatives nor to discuss the advantages and disadvantages of each. There is much published information on the subject to turn to, particularly in the Proceedings of the American Wood Preservers' Association, the publications of the U. S. Forest Products Laboratory, and the publications of responsible preservative manufacturers. The following paragraphs, however, point to some of the things we can turn to in time of necessity.

Some Words of Caution

For protecting wood pile structures in salt water, use only the best grades of coal-tar creosote or creosote-coal-tar solutions and treat the wood to refusal. No other preservatives can be counted on for long life in salt water and, with most of them, the protection will be slight. If other preservatives must be accepted, or if low retentions of creosote or creosote-tar mixtures must be allowed, limited life should be expected and a written record should be made to show that it was not possible to provide the kind of treatment required for reliable performance.

The Right Preservative for a Given Use

For railway ties, there are many products that may be used to supplement the standard treatments or in complete substitution, but they should be used with considerable skill and intelligence to avoid serious difficulty or sacrifice of quality. Coal tar, water-gas tar creosote, lignite-tar creosote, wood-tar creosote, and oil-tar creosote are some of the oils that have been used in the past for adding to coal-tar creosote or in lieu of creosote. Each of these oils may vary widely in quality, some compositions being of such toxicity, cleanness, and general character that there need be little hesitation about using them while others have serious deficiencies that need to be avoided. Before any oils are mixed together in large quantities, studies should be made to determine whether they are mutually soluble and can be mixed and heated repeatedly without forming a sludge. When solutions of pentachlorophenol are used, addition of other oils may throw some of the pentachlorophenol out of solution, particularly on repeated heating and cooling. This, of course, should be avoided.

Solutions of pentachlorophenol in petroleum of suitable quality can be substituted for creosote or creosote solutions in tie treatment, as long as they remain available.

For the treatment of poles, oils that leave the wood surfaces sticky or oily are undesirable. This makes the choice of substitute oils more limited than for tie treatment. During World War II, pentachlorophenol solutions were used in large quantities for pole treatment, either alone or in mixture with creosote. Copper naphthenate solutions also found considerable use in the same way. Mistakes were made and some unpleasant experiences were encountered at times in adapting these solutions to plant practice, but with appropriate oils and proper care they should prove satisfactory and give good protection.

For piles, posts, and structural timbers for land use, much the same preservatives can be used as for ties, although in some such uses, cleanness may be considered of greater importance than for ties.

Water-Borne Preservatives

In using water-borne preservatives, the problem is not one of diluting one material with another but one of substitution. The standard materials should be used and standard specifications followed as long as that is practicable. When they are no longer available we may have to turn back to straight zinc chloride or even use such materials as sodium fluosilicate, borax, boric acid, or zinc sulfate, all of which are known to have some preservative value but are less desirable than the preservatives in normal use.

Judgment Required

Turning to a second- or third-choice preservative may jeopardize considerable values and should be done only after careful study of all the factors involved. Sometimes it may be brought about through emergency specifications lowering the requirements of the standard Government or association specifications. This is usually done through committee action, after study. Railroads buying preservatives for the treatment of their own material have freer choice and can buy what the market provides. The individual purchaser of treated wood, however, may be faced with a "take it or leave it" choice. Commercial wood-preserving plants seldom can carry more than two preservatives and are not in position to let their customers choose at will from a long menu. Whatever the circumstances, the over-all problem is the same, namely, to get the best protection at the most reasonable cost under the prevailing limitations and restrictions. That will require good judgment—and a lot of good luck, too, if restrictions become severe.

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Discussion

Edward Garbus (Michigan State College): Is the reduction in the use of wood preservatives such as zinc chloride, Wolman salts, copper naphthenate, etc., not including creosote and other coal-tar preservatives, due to the difficulty in obtaining the chemical or to cost factors?

Mr. Hunt: Fluctuations in the amounts of different preservatives used are due in part to competition and to variations in character and quantity of materials being treated. The cost of copper naphthenate puts it in a weak competitive position when the supply of preservatives is plentiful. Then there have been some unfortunate failures of material supposed to have been treated with copper naphthenate solutions. This has adversely affected the reputation of copper naphthenate, although possibly unjustly. I think normal business competition has much to do with fluctuations in the amounts of Wolman salts used. With both copper naphthenate and Wolman salts, I believe there has been no shortage of supply.

R. N. Hammond (Weyerhaeuser Timber Co.): What experiences are available on the use of pentachlorophenol in petroleum oils for the protection of wood against marine borers?

Ira Hatfield (Monsanto Chemical Co.): All service records to date indicate petroleum solutions are not effective in salt water.

Ralph H. Mann (American Wood Preservers' Association): Is the quality of creosote in use today as good as that used 25 to 50 years ago?

Mr. Hunt: The character of creosote varies somewhat from different producers and from time to time as demands for some of the normal constituents of tar or creosote vary. So far as I know, however, the good creosotes of today are just as good as the good creosotes of 50 years ago. There were creosotes then and there are creosotes today that seem less desirable than others but all coal-tar creosotes that honestly meet standard specifications as to source and character may be relied upon.

E. M. Conway (Tennessee Valley Authority): Are any of the standard preservatives critical at the present time?

Mr. Hunt: The salts of zinc and copper may be in short supply because of the increased demand for these metals.

George E. Olson (Dow Chemical Co.): We have been handling all requirements for chlorinated phenols.

E. H. Rieman (DuPont Company): We are not looking for any greater volume of sales of zinc or copper salts.

H. W. Angell (American Lumber & Treating Co.): There is thus far no shortage of Wolman salts.

Kenneth T. Scudder (Taylor–Colquitt Co.): Are creosote products capable of being produced from petroleum more cheaply than from coal tar?

Mr. Hunt: Many patents have been issued on the preparation of creosote from petroleum but no such creosotes are known to be in commercial production. It is not impossible that perfectly satisfactory preservatives of this character may ultimately be produced from petroleum that will be acceptable and competitive with coal-tar creosote. Many years of testing and observation will be required, however, before they will find general acceptance as the equal of coal-tar creosote.

The Broader Aspects of Wood Preservation with Particular Reference to Creosote

JAMES N. ROCHE, *Koppers Company, Inc.—Tar Products Division, Pittsburgh, Pa.*

The writer presents information about one of the horizontal levels of the organization—the wood preserving industry. The information is largely statistical.

THE wood preserving industry is a large industry. The yearly value of its products are reported in terms of hundreds of millions of dollars.

Why Does Wood Need Preservative Treatment?

Man and wood have been associated for as long as man has been on this earth. Over the centuries that have passed since this acquaintanceship began he has learned, though he may not have understood why, that all untreated wood in contact with the ground will eventually be destroyed, either by fungi or by insects or by the two working together. He has also learned that his untreated wood structures standing in sea water will be destroyed by marine borers. Man's desire to build permanent structures in order to hold down replacement and maintenance costs led to the development of the wood preserving industry.

The part which termites and other insects played in the destruction of wood structures on land and the part played by teredo and other marine borers in boring into wood for shelter or for its use as food was something that man could see and understand. More subtle was the action of fungi. These organisms, unable to grow in dry wood, attack moist wood when its water content approaches 25 percent. They feed upon the wood cells and break down the wood as they grow. Evidence of their growth and of the attendant decay of the wood is often first signalled by a growth of mushrooms, "squirrels ears" and the like from the wood, these being the fruiting bodies of the fungi at work within the wood.

Though only imperfectly understanding the processes of decay and deterioration, man began to take his first practical steps to prevent the destruction of his wooden structures well over 100 years ago. About 75 years ago, modern wood preservation got its start when he learned to force coal tar creosote into the wood pressure in closed cylinders.

Through one of those happy coincidences, creosote proved adequate and effective against all three of the diverse agents of wood destruction—fungi, insects and marine borers—and at the same time it met the almost equally important requirements of permanency, commercial availability at an economic price level and low toxicity toward humans and animals.

The diverse uses to which wood is put and the various complexities of application and use make it impossible for any one preservative to have the field of wood preservation to itself. Thus it is that the modern wood preserving industry offers a number of preservatives for treating wood. For example, water solutions of salts of zinc, copper, arsenic and the fluorides, as well as copper naphthenate and pentachlorophenol in petroleum solvents are used for such items as stadium seats, sash and trim, boardwalks and railway platforms handling cotton, to mention only a few instances where for one reason or another creosote would not be used. Most of these preservatives, like creosote, are backed by long and excellent performance records under actual service conditions.

Who Uses Treated Wood

The major users of treated wood are the essential transportation, communication, electric light and power, shipping, mining and building industries and the farmer. The types of treated wood are diverse but it is a tribute to the universal use of wood that the same item is often used by several industries:

> Cross ties, switch ties, bridge and trestle timbers, poles, cross arms, conduit, piling, sway braces, planking, culverts, sea walls, construction timbers, wood blocks, car lumber, fence posts, guard rail posts, mine timbers, pipe staves, pens, corrals, platforms, boardwalks, sash, trim, doors, outdoor furniture and other milled lumber.

Such treated wood has a greatly extended service life. Fully creosoted telephone poles, for example, can be expected to last 40 to 50 years. Untreated railway ties which last about 5 years by treatment may last 25 years, even under the severe conditions of railway traffic. Creosoted piles driven into the ground are permanent.

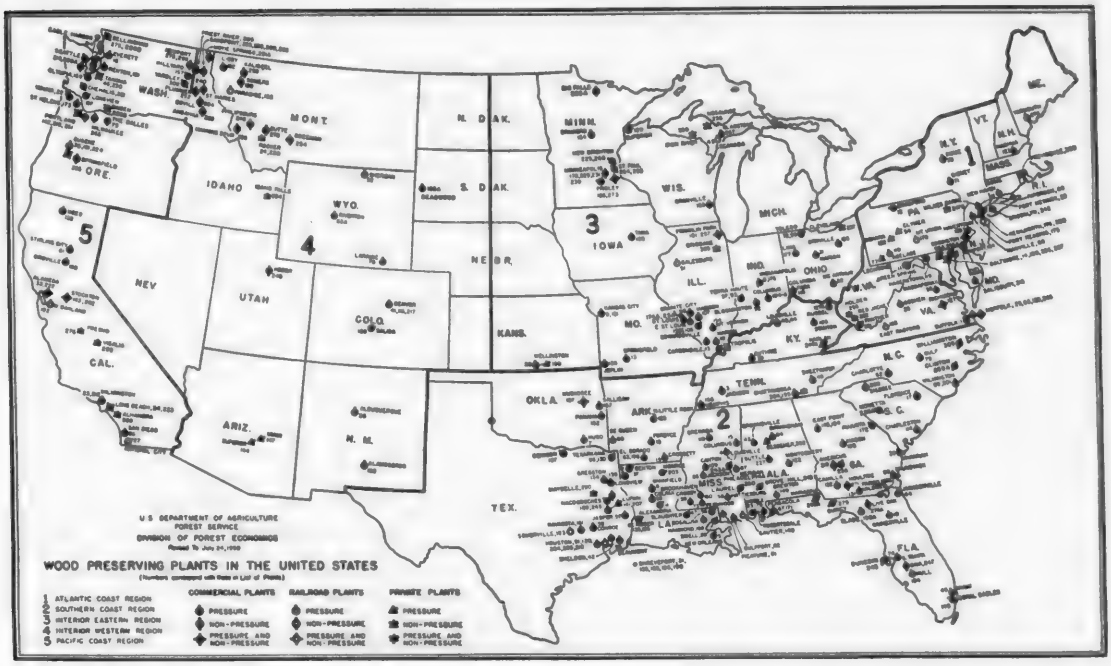

Fig. 1.—Wood preserving plants in the United States.

Distribution of Wood Preserving Plants in U. S. A.

The scope of the industry and the location of its nearly 300 wood preserving plants are shown by Fig. 1 which is reproduced from the Wood Preserving Statistics section of the 1949 issue of the Proceedings of the American Wood Preservers Association.

Preservatives Used in 1949

The consumption of preservatives by amount and by name are shown in Table 1 which is also reproduced from the Proceedings just cited.

TABLE 1.—CONSUMPTION OF PRESERVATIVES—1948–1949

Liquids	1948	1949
	Gallons	
Creosote and coal-tar		
Creosote		
Creosote content of		
Creosote petroleum solution	25,264,127	23,782,622
Creosote petroleum penta solution	1,634,099	1,694,287
Creosote petroleum copper naphthenate solution	59,068	0
Creosote coal-tar solution	31,929,155	34,720,277
Straight creosote	106,684,293	110,196,806
Total creosote	165,570,742	170,393,992
Coal-tar		
Coal-tar content of creosote coal-tar solution	15,241,962	16,755,405
Creosote coal-tar solution not broken down	16,605,793	13,355,555
Total creosote and coal-tar	197,418,497	200,504,952
Solids	**Pounds**	
Straight zinc chloride	251,322	0
Chromated zinc chloride	4,254,569	2,903,587
Wolman salts	1,286,302	1,003,992
Celcure	218,137	138,829
Pentachlorophenol, used in solutions with petroleum and creosote-petroleum	2,909,314	2,288,614
Copper naphthenate, used in solution with creosote solution	31,755	0
Osmose	0	80,871
Copperized chromated zinc chloride	0	98,703
Protexol	581,302	678,341
Minalith	405,603	197,927
Miscellaneous	612,259	410,299
Total solids	10,595,563	7,801,163

Comparison of Preservatives Based on Volume of Wood Treated

The information on comparative volumes of wood treated with various preservatives appears in table form in the Proceedings just cited and is shown here as Table 2. It is seen that a very high percentage of the total volume of wood treated is treated with creosote as the preservative agent. Such is the size of the industry, however, that the volume of wood treated by the preservatives other than creosote in 1949 is nearly sufficient to make a boardwalk two feet wide extending around the world at the equator.

TABLE 2.—COMPARISON OF PRESERVATIVES BASED ON RELATIVE VOLUMES OF WOOD TREATED—1949

	Cubic feet wood treated
Creosote	269,913,829
All other preservatives	20,642,105
	290,555,934
Treated With:	**Per Cent**
Creosote (includes Creosote-Coal Tar and Creo.-Pet.)	92.89%
Pentachlorophenol—petroleum	2.14
Creosote-Penta-petroleum	1.46
Chromated Zinc Chloride	1.30
Wolman Salts	1.12
Celcure	.05
Miscellaneous	1.04

Imports of Creosote

The creosote picture would not be complete without reference to imports. During 1949, the imports of creosote amounted to 16 percent of the total creosote consumed. Imports by countries for 1950 have just become available. Table 3 shows the origin of import oil by countries.

Summary—Outlook

Untreated wood in contact with the ground and similar wood exposed to marine borers in sea water has a comparatively short service life. Treatment of this wood with preservatives under pressure adds permanence.

The major users of treated wood are the essential transportation, electric power, communication, shipping and mining industries. From the standpoint of economy, these industries recognize that they can no longer permit untreated wood to be used in any situation where preservative treatment would result in more economical maintenance. Such a program is also in the best interests of our national economy.

Thus, it is that preparations for war which might envisage a return in part at least to untreated wood call for scrutiny of the supplies and availability of preservatives. Government action to date in limiting copper and chromates indicates some tightening in the supply of preservatives containing these materials. Although pentachlorophenol is made from phenol, which in turn is made from benzol, now in great demand, there is no indication that supplies will be decreased. As this is written, we have not as yet seen anything that would lead to any particular shortage of creosote. The demand for treated wood during 1951 appears to be heavy. This will mean more creosote consumption, but producers are already expanding their distillation programs to handle increased customer requirements.

Developments in times of past national emergencies which affected creosote supplies, and which will therefore bear watching in the present emergency, were (a) sharp shortages in fuel oil supplies and (b) difficulty with transportation facilities, particularly ships. With regard to fuel oil, it will usually be found that in times of shortage, steel companies turn to burning tar for fuel in their open hearth furnaces. This, of course, results in less tar being available for creosote manufacture. Reductions in available tanker space would be reflected in lower import quantities and possibly in poorer distribution to areas such as the West Coast.

TABLE 3.—CREOSOTE IMPORTED INTO THE UNITED STATES—1950

	United Kingdom	Belgium	Canada	Netherlands	Germany	Mexico	
January	3,995,107	1,690,702	———	———	———	———	
February	690,619	———	———	———	———	———	
March	———	———	90	1,999,515	———	———	
April	4,914,606	102,556	10,468	———	987,176	———	
May	———	———	———	———	———	———	
June	2,592,974	1,075,346	———	300,000	———	———	
July	3,196,151	382,156	5	———	1,340,421	———	
August	1,733,498	———	———	2,158,559	1,476,906	12,340	
September	300,390	1,744,808	———	2,519,948	833,542	———	
October	94,207	———	5	———	509,903	———	
November	1,034,195	———	10	———	1,656,051	23,871	
December	2,890,538	———	24,445	———	1,357,829	———	
Total	21,442,285	4,995,568	35,023	6,978,022	8,161,828	36,211	41,648,937

Discussion

E. M. Conway (Tennessee Valley Authority): Are any of the standard preservatives critical at present time?

E. H. Rieman (DuPont Company): Present supply of zinc salts is generally short, nation-wide. We are at present in a position essentially to meet requirements of regular customers for CZC-chromated zinc chloride, and Copperized CZC, but do not anticipate, at present, ability to acquire new commitments.

Ted C. Weill (Michigan State College): Are heartwood ties treated?

Mr. Besher: Yes, some heartwoods of some species treat very well, such as black gum, red oak, elm, western yellow pine, etc. If heartwood ties are adequately seasoned and then pressure creosoted, all species of ties give long and satisfactory life, providing they have the other necessary physical characteristics, particularly resistance to splitting and checking in the track.

Mr. Conway: What is market status of treated railroad ties?

Mr. Roche: The railroads stopped buying ties because of increased cost, now with war on, an extreme shortage of crossties has developed.

H. W. Angell (American Lumber & Treating Co.): Creosoted structures are partially fire-retardant —is there any idea as to the mechanism involved?

Mr. Bescher: There are records in the literature of numerous fires in creosote structures which have burned vigorously from a half to two hours and then extinguished themselves without too serious damage to the structure. Creosoted wood burns similar to kerosene burning on the wick of a lamp. Thus, the burning of the creosote in part lowers the rate of burning of the wood. The creosote having a very high carbon to hydrogen ratio burns with an extremely sooty flame. Frequently there is sufficient soot deposited on the surface of the burning wood to smother the fire.

Edward Garbus (Michigan State College): Is any work being done on creosote to remove its objectionable characteristics, such as odor?

Mr. Roche: We have considered it but no work is in progress. The cost of removing odor would probably be exhorbitant.

George M. Hunt (U. S. Forest Products Laboratory): Perhaps an odorless creosote would be useful if it could be obtained at reasonable cost and without reducing the effectiveness of the oil. It does not seem to be a matter of great importance, however, for there are odorless preservatives that may be used instead of creosote in most places where creosote odor is seriously objectionable. Waterborne preservatives are usually odorless, and wood treated with pentachlorophenol solutions need not have a strong odor.

G. G. Garlick (Protection Products Mfg.): What is the purpose of incising?

Mr. Hunt: Incising increases penetration in many species, particularly Douglas fir, in which the longitudinal penetration is sufficient to permit penetration along the grain from one incision to another. It is not effective in the heartwood of white oak and red gum, however, because longitudinal penetration in these species is too limited.

Ralph H. Mann (American Wood-Preservers' Association): Can hardwoods be successfully treated?

Mr. Hunt: More than half the crossties treated are hardwoods. They treat about as well and benefit as much by treatment as the softwoods. Even white oak, which is naturally durable, has its life more than doubled by creosote treatment, and red oak, which has low natural decay resistance, is made by proper treatment approximately equal to birch, maple, and the gums, which also are treated but in smaller quantities than the oaks.

Robert W. Wellwood (University of British Columbia): Is the mechanism by which creosote preserves wood well understood?

Mr. Roche: Yes, on the basis of Bateman's classic work at the Forest Products Laboratory.

Charles S. Walters (Illinois Agricultural Experiment Station): Perhaps the correct answer is that the food of the fungi, cellulose, is poisoned.

Mr. Hunt: No one knows all the detailed mechanisms involved in the protection of wood by creosote. Briefly and in simple terms, however, creosote is poisonous to wood-destroying fungi and insects and these organisms cannot live in wood that has substantial quantities of creosote in it. Mr. Walters put it more succinctly when he said the food of the wood destroyers is poisoned.

Mr. Walters: How does birch treat?

A. J. Loom (Northern Pacific Railway): About the same as maple. Standard practice for preservative treatment of Minnesota–Wisconsin birch ties by the Lowry process at the Brainerd, Minnesota, plant of the Northern Pacific Railway, with 50–50 creosote-petroleum solution, (A.W.P.A. Specification P 3–48 is as follows: Ties are air seasoned from six to twelve months before treatment. Green ties to be adequately seasoned for treatment in October should be piled in the seasoning yard not later than May 1st. Treatment is in accordance with A.W.P.A. Specification T 1–49, and consists of the following.

Temperature of preservative—180° to 190° F.
Pressure from 1 to 2 hours—100 to 150 pounds per square inch.
Vacuum 1½ hours—22 inches.
Net absorption—8 pounds per cubic foot.

Mr. Weill: Are the companies overcoming difficulties found in creosote treatment of heartwood in species used for ties?

Mr. Bescher: The problem of getting deeper penetration in the heartwood of species which are resistant to penetration of creosote is very difficult. If the heartwood ties can be fully seasoned and all season checks are developed before treatment takes place, the tie is adequately protected because there will be a film of treated wood completely surrounding the susceptible untreated heart center. However, if the ties check subsequent to treatment and check deeper than the treated shell, the center of the tie is subject to decay.

TECHNICAL SESSION VI—Thu., May 10, 1951, 9:00 A. M.

General Subject: Training Men for the Wood Industries

Chairman: R. C. Fraunberger—Recorder: R. A. Hertzler

What the Furniture Industry Expects From the College-Trained Man

CLYNE CRAWFORD, *President, Crawford Furniture Manufacturing Corporation, Jamestown, New York*

The furniture industry needs college men with sound technical training, able to apply basic science to the industry's many problems without reference to traditional thinking, with integrity based on good moral training, and the ability to understand and work with people.

WE ARE a very great industry made up of relatively small units. That simplifies our problem in some respects in dealing with the college-trained employees, as we do not have to guard against over specialization and its discouraging routine. Instead, we need men more versatile than the great corporations which have a tendency toward specialization.

The Men Needed

We need men as future supervisors and executives with three general qualifications when they leave college.

1. To approach the problems of the furniture industry with a critical and analytical mind and not to accept hide-bound tradition as either necessarily right or wrong.
2. To be as familiar as possible with much of the research and academic knowledge pertaining to these problems.
3. To deal intelligently with people.

About two years ago, I was asked to present a paper on some of the problems of the furniture manufacturer. Fortunately, I was not asked to solve them. Among the problems mentioned was that of open glue joints. I said it was still a mystery to me what caused them in spite of all the papers written on the subject.

I received a number of letters with regard to this paper, most of them suggesting there was no mystery to making good glue joints. One professor proposed that if I would outline all the conditions under which these glue joint failures developed, he could readily locate the trouble. The very simplicity of this effort to be helpful, implying that four or five well-established basic facts would solve the problem, shows how little many of even our better informed men know about the many variables involved in one of the fundamental problems.

The available knowledge concerning the basic facts of wood gluing is extremely meager. What pressure should be exerted on the glue line when hard maple, for instance, is being used, and what moisture content of the wood results in the best joint? What time element for drying is necessary under different drying temperatures? Certainly the answers are not the same for urea resins and animal glues or for edge gluing and lying up veneers. In fact, the answers are so complex that much research must be done before we have working formulas upon which intelligent decisions can be based.

On a problem of this kind, we do not expect the college-trained man to know all the answers, because most of the answers are still to be established. We can, however, expect him to know what the problems are and to be logical and thorough in his analysis of them. He should not be dogmatic in his thinking.

Need for an Open Mind

I was talking to a plant owner the other day about glue joint problems, and he said, "Well, I know one thing—the lumber should not have over 5 percent moisture content." This man used four different types of lumber and both animal glue and urea resin in his factory, yet he felt he could generalize to that extent. This is not the type of approach we expect from a technically-trained man. We do not expect him to be an expert in all fields, but we do expect him to have an open mind free from the old traditions of the industry and to be able to recognize problems and the factors that make the problems even though he might not have the ready answers. He should be able to isolate and classify the variables of a problem and to establish a plan to solve it.

Varied Skills Are Useful

Besides knowledge on wood seasoning and gluing, it is also very desirable that the college-trained man have some knowledge of the design of machinery and on the machinability of wood. A working knowledge of cutting forces, cutter efficiency, and power requirements for modern woodworking machines is extremely essential. This is another field in which additional basic knowledge should be developed through research at our federal, state, and

university laboratories. We can no longer rely on "cut and try" methods to obtain lowest production costs, greatest output and highest quality.

We also expect this advanced training to teach a man fundamental principles so that his thinking evolves from a firm foundation. A study of basic principles is more important than many so-called "practical" courses. Fundamental principles of engineering and the sciences are essential. The principles of economics and principles of accounting are invaluable, since most of the furniture plants are too small to employ several specialists. The principles of religious values, which are frequently overlooked yet which assure his integrity and high ethical standards and practices, are of utmost importance.

There are other subjects which are desirable other than the principles just mentioned upon which thinking and logic are founded. One important one to a technologist is the ability to make simple but interpretive free-hand sketches. This is needed in production and sales, in the design of forms and tools, the design of furniture, or detailed parts of furniture, and for explaining ideas to the administration as well as to fellow employees. It is an ability which can be developed with instruction, but few people possess it in spite of the fact that everyone in the furniture industry wishes he had acquired such training.

The study of fundamentals of statistics trains the mind to classify varying causes and effects and to evaluate them, a function particularly needed in the furniture industry. The knowledge of statistics encourages the individual to look beyond the published reports to question and to interpret stereotyped facts.

People Part of the Job

In addition to the technical problems peculiar to our industry, another important problem which we expect the college-trained man to approach with intelligence is that of dealing with people. Industry is assuming greater social responsibilities, and the handling of human relations is a very important phase of the work of supervisors. Many college students to whom I have talked before they were graduated thought that most management-labor problems were due largely to the unreasonableness of management. Soon after they had their first experience in supervision they often felt the factory employees were extremely unreasonable in their demands. A good supervisor is one who does more than just get along with people; it means getting the job done with harmonious relations continuing to exist between the employees and also between departments. The ability of an individual to be firm but courteous is a requisite to success as a supervisor. We expect college-trained men to know more about the problems of human behavior than men who have risen from the ranks due to their technical skill.

A college graduate should be willing and eager to join the clubs or groups of his own professional training and to take part in their activities. He should be willing to do his part in civic enterprises and to maintain an association with men similarly situated in his field.

Opportunities and Rewards

The furniture industry is made up of smaller corporations than some industries are. Therefore, we cannot afford the specialization for an individual function that some large industries engage in. Our supervisors must have a well-balanced and more versatile educational background. A supervisor in the furniture plant is less inclined to be straight-jacketed than in a larger organization. He has an opportunity to express his technical knowledge, leadership, enthusiasm, imagination, and vision. The furniture industry offers greater opportunities to a college man, because he can more readily express his complete personality. Research in adhesives, lumber, and machinability of wood promises great progress for the industry. Progress is the very basis of opportunity. We demand a great deal of the college graduate, but at the same time we feel, as the future will show, that we have a great deal to offer in exchange.

Discussion

Theodore C. Weill (Michigan State College): What kind of college training is necessary?

Mr. Crawford: Liberal arts training is necessary for an executive's progress but the furniture industry is behind technically, and needs men trained in fundamental principles if the industry is to make progress.

Wayne K. Murphey (Pennsylvania State College): Your emphasis on a longer college education raises a question. Do you think that a Master's degree or 5-year course is indicative of a man's ability to fit into industry? Many people in industry are not college men. How can you get analytical thinkers from college? If a man will get the basics wanted by industry, while developing a logical mind, is it not possible that such a man will be more acceptible to the industry?

Mr. Crawford: The most valuable man in his outfit doesn't necessarily have a high school education, but he studies all the time, including night school courses. Academic training should be taken in college. In college he should get cultural training and not do too much outside work earning expenses unless absolutely essential. If a man has ability to get an education outside of college he is usually an

excellent man who would do even better with college training. College is the easiest way to get training.

Dr. Hereford Garland (Michigan College of Mining & Technology): What is the best way to start a college graduate learning furniture manufacturing?

Mr. Crawford: By working in a furniture factory on jobs that are not too confusing, such as inspecting, checking moisture content of lumber throughout the plant, as production control clerk, handling routine personnel problems such as interviewing applicants and other work that takes him around the factory.

Mr. X: What will be the effect of greater research to the economic position of the furniture industry?

Mr. Crawford: When some of the fundamental problems besetting the furniture manufacturer are minimized by research on glues, lumber, machinability, humidity and its control and finishing materials, there will tend to be much larger and modern furniture factories with sales and advertising problems, as well as designs more intelligently handled as manufacturing facilities can be expanded under the same general supervision and overhead. Furniture costs will come down with this expansion.

Mr. X: What will be the effect of training men in the universities for the furniture industry?

Mr. Crawford: A more satisfied working force in the factory where they are handled with intelligence. There will be greater opportunities for those of ability when intelligently directed and observed.

Mr. X: How can research in the furniture industry best be advanced more rapidly?

Mr. Crawford: By trade associations supporting the intelligent research now being carried on in accredited colleges. Every phase of the industry should be interested in this research, the manufacturers, the glue sources, manufacturers of finishing materials, the hardwood associations, and dealer associations interested in a better product for less money. All these associations should be acquainted with what research is underway and its objectives.

The Scope and Objectives of College Training "Undergraduate Training"

F. H. KAUFERT, *Director, Minnesota School of Forestry*

The rapid post-war development in college training programs in the field of wood processing and merchandising is summarized. Forestry, engineering, and business schools have been primarily interested in this development. The important problem of attracting and holding qualified staff members with experience in industry and the part that industry can play in accomplishing this is discussed. The added problem of attracting to these college training programs more high quality, interested, and stimulated students is emphasized.

Introduction

THERE has been a remarkable growth of undergraduate college training programs having as their objective the preparation of students for employment in the wood-processing industries and in the merchandising of wood products. Schools of forestry, engineering, business administration and combinations of these groups have all been interested and involved in this growth and development. Much has been written on the success or failure of these programs and the product they have turned out—the young men with B. S. degrees whose objective is to find and make places for themselves in the wood processing and merchandising field.

It is difficult for any one individual to attempt to encompass and summarize all of the developments in training for employment in the wood processing and merchandising fields which have taken place in such diverse groups as forestry, engineering, business administration and other schools or colleges. It is even more difficult for one individual, regardless of how well he may be generally acquainted with wood technology developments, employment opportunities, and achievement of graduates, to evaluate with any degree of accuracy the success of training programs of this type. It is probably much easier to enumerate and set forth what one considers the shortcomings and problems of undergraduate training aimed at preparing students for employment in the wood processing and merchandising fields. Consequently, in approaching the subject, I do so with considerable hesitance, recognizing that to every general statement made in this paper there are glaring exceptions.

In this discussion the assigned subject will be treated from the standpoint of developments that have occurred in schools, colleges and universities preparing students for these fields of employment; the type of product that has been produced, the acceptance of this product by industry; and the problems of these college training programs and what may be done to cure or correct them.

Development of Training Programs

It is not the purpose of this paper to go into great detail concerning the development and expansion of training programs in this field. Those who read the series of articles in Wood Magazine (1947–49) have had some introduction to what has happened in several forestry and engineering schools in connection with such training. Anyone doubting the interest that forestry schools in particular have taken in developing training programs in this field should read the excellent discussions on these developments written by Dunn (*1*), Garland (*2*), Hossfeld and Rees (*4*), Jeffers (*5*), Korstian (*6*), Marckworth (*7*), Panshin (*8*), Patronsky (*9*), Stevens (*11*), and others who have covered developments at their respective institutions in articles appearing in Wood Magazine and other trade publications. Briefly, the outstanding feature of each of these discussions appears to be the expression of deep interest in the further development of these training programs, the tremendous increase in equipment and space devoted to this training, and the somewhat increased staff devoting its time to this field of training.

Additional discussions of developments in training, particularly in fields commonly designated as wood technology and wood utilization have been further summarized and described by Preston (*10*) and the several publications of the National Lumber Manufacturer's Association (*12*). In all of these discussions, relatively little attention is given to what may prove an equally significant development in training for this field. This field of training is what has been designated as preparation for sales and development work in the field of building products merchandising. While not concerned primarily with wood, this development has outstanding significance because one of the recognized weaknesses of wood-using and processing industries has been in sales and merchandising. This growth in interest on the part of forestry and engineering schools as well as, very fortunately, on the part of business schools, has been described by several individuals and has been widely publicized in trade journals. However, the writer questions whether the signficance of this development is fully appreciated by most individuals concerned with training for production of wood products. We are too prone to consider the laboratory with its hot presses, dry kilns, pressure treating cylinders, saw mills and other paraphernalia as a measure of accomplishment. Actually, little of this is necessary, nor need it be used in the training of successful building products merchandisers. The writer is the first to admit that a good basic knowledge of products is essential to the merchandiser. However, such knowledge does not necessarily have to be obtained through exten-

sive laboratory course work. It can probably be equally effective and valuable if obtained through plant visitations, illustrated lectures, etc.

Although this is a rather rough estimate and is based primarily on the discussions of equipment now available for instruction as given by the several authors quoted above, the writer is convinced that there has been at least a four-fold increase in materials available for instruction in these fields as contrasted to that available prior to World War II. Materials in this case would include laboratory equipment, space and literature. In regard to staff increases, it appears that this has not been as rapid. Judging again from the reports available in literature, there are today approximately two times as many individuals engaged in training students for these fields as there were prior to World War II.

In regard to another important item on which one can judge development, interest, there appears to have been a far greater development than in either of the above. It is recognized that interest alone is not sufficient to bring about accomplishment. However, sustained interest on the part of many individuals when combined with growth and strengthening of training facilities imparts additional significance to the happenings of the past ten years in this field. That there has been increased interest in these training programs is further indicated by the number of students being trained. Preston (*10*) suggests that this number is at least double the number trained prior to World War II.

The Product of This Training

In discussions of research results and product development, the ultimate measure of success is usually determined by the acceptance or success of the product produced. The product produced by all of the training programs is the graduate with the Bachelor of Science degree. In his normal four-year training program he has been exposed rather generally during his first two years to a basic series of courses in the natural and social sciences, English and a few elementary courses which will serve him as background material for later professional courses. During his last two years in these training programs, he is subjected to a rather diverse set of professional courses, most of them largely introductory, in such subjects as wood identification, seasoning, gluing, wood products, plywood, woodworking machinery, wood preservation, pulp and paper, wood chemistry, etc. During these last two years he has had exposure in the larger and better equipped institutions to the manufacture of wood products in one or more laboratory courses. He has at least learned what hot presses, pressure treating cylinders, dry kilns, wood testing equipment, etc. are used for and has some knowledge of their operation. If the student has been fortunate enough to have several summers of experience, he may come out of these training programs better prepared and with more to offer prospective employers than without such experience.

I am in agreement with the opinion expressed by Graham (*3*) in his recent article "Industry wants college men, but with practical training". Graham emphasizes the combination of class room and practical training which is so desired by prospective employers. Few would argue with the thesis he develops on this subject. However, a critical analysis of what can be successfully encompassed by a student in a four-year program leading to the Bachelor of Science degree leads one to the following general conclusions:

1. That with the exception of the occasional individual, students with outstanding ability and fortunate enough to have gained broad experience through summer work or other employment, the average graduate of these training programs has been an individual with training deserving the award of the B. S. degree, but certainly not adequately prepared for specialized work in any particular industry. In other words, it has not been possible, and I am certain that the future will provide additional proof that it is not possible, to train in undergraduate training programs specialists in such fields as wood preservation, plywood manufacture, seasoning, gluing procedures, etc. The writer is convinced that schools attempting to accomplish such specialized industry training on the undergraduate level will find their programs more on the vocational than college level. This statement is not meant to imply that vocational training is any less important or less to be desired than college training. Actually, the writer considers vocational training for the wood processing and merchandising industries one of the most important and significant parts of all training. What is implied, however, is that it is difficult in our wood technology, utilization and merchandising training programs to train specialists capable of taking their place immediately upon graduation in given industries.

2. That institutions training men for the wood processing and merchandising fields can claim some credit for the success of their graduates in these fields. It is not necessary for me to report to you that most institutions make such claims. In my opinion, it is unfortunate that these claims for the success of graduates are usually based on the amount or practical instruction given students in applied subjects. This is unfortunate because it is so evident that what we can and should attempt to achieve in training for the B. S. degree in four-year courses is emphasis on fundamentals, on principles, on background basic training that has general but not specific application. When we attempt to go further and train for specific industries, there is usually a compromise and the question arises—is the training at the college level or is it vocational?

Although there is bound to be plenty of disagreement on this point, it is evident to me that highly specialized training or training for employ-

ment in branches of the wood processing and merchandising fields has little place in the undergraduate college program. Such training must be obtained through summer work, on-the-job training following graduation, and through starting at the bottom and learning through doing on various jobs. Training for specialized research and development work in industry belongs in the graduate and not undergraduate fields.

Problems of College Training Programs

In my opinion, the problems of undergraduate training programs at the college level, are not lack of large laboratories with their array of equipment so dear to the heart of wood technologists, engineers, and students. Equipment and facilities of this type are impressive to prospective employers and often tend to confuse them regarding the merits of the product—the graduate with a B. S. degree in wood technology, utilization, engineering, or merchandising. Such equipment and laboratories, though impressive, are little more than accoutrements or window dressing for undergraduate college programs, whereas they are necessities for vocational and graduate training programs.

The problems of undergraduate training programs, it appears to me, are lack of a sufficient number of qualified staff members and failure to attract a larger number of outstanding students.

With few exceptions, engineering schools offering training in this field do not include on their staffs men with a thorough background of training in or appreciation for wood products. It is difficult to interest students in a raw material with the diversity and complexity of wood if the staff member is not fully appreciative of its properties and potentialities. Forestry schools have done more to increase their staffs for such training. However, these increases have too frequently been more in quantity than quality. The individual with ambition, imagination, ability to stimulate students, and possessed of other qualities needed in good teachers has too frequently avoided or only briefly tarried in educational institutions. For this situation industry must assume its full share of responsibility. This responsibility lies only partly in the fact that industry has drawn so many promising teachers to its ranks. A more important contributing factor is that industry has not assumed sufficient responsibility for seeing that the institutions from which their future leaders should come have the support needed to improve salary levels to the point where a larger percentage of outstanding and successful men with promise as teachers return to the teaching field after they have made their mark and have gained the broadening experience so badly needed.

The effect of such industry support for college training programs is being felt all along the front of American education. The agricultural products processing industries, through their interest in college training programs, have done more to improve the quality of instruction in this field than could have been accomplished by a century of pleading by staff members and college administrative officers. The same can be said for several fields of engineering, for business administration, and other training specializations. It is high time that the wood-processing and merchandising groups increase their efforts along this line if we are to improve our most important instructional element—the professor.

Many papers have been written on the quality of the students attracted to these college training programs. In general, the quality has been only fair. There have been outstanding individuals to be sure, but the average has probably been lower than for such fields as mechanical and electrical engineering, medicine, and possibly even the agricultural products-processing field. Too few students enter directly into these programs. They come in after they have started in other fields and have by some means gained an acquaintance with the opportunities in wood-products processing and merchandising. The correction of this weakness is the joint responsibility of industry and the schools. That it can be accomplished is indicated by the improvement in student quality achieved when industries have joined with schools in publicising training programs, employment objectives, and employment opportunities. Here is a challenge to the wood processing and merchandising industry, a challenge that it has attempted to meet in piece-meal fashion in the past and with promising but limited results.

Summary

Developments in college training for the wood-processing and merchandising fields have progressed rapidly since World War II.

There have been outstanding gains in laboratory facilities at many institutions, added attention to course offerings, and some improvement in teaching staffs.

Several industry associations and a number of manufacturers have developed greater interest in and have given support to the programs in several institutions. These developments, although encouraging, have fallen far short of the need.

The important problems facing most schools in the further development of these training programs are not only the need for added space and equipment, important as these items are. They are rather the problems of: (1) Attracting and holding staff members with experience, imagination, and ability to teach; and (2) attracting more high quality students through cooperative effort with industry.

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Discussion

Newell A. Norton (Pennsylvania State College): What complications with regard to labor unions do wood-processing plants face when considering the employment of students for summer work, through which students can gain badly needed experience?

Mr. Kaufert: In some plants the labor union situation is such that students cannot be employed even for summer work. Many employers have worked out satisfactory arrangements with unions on this point and these permit student employment as trainees. In some plants the students must join the union in order to be employed. This is still a very difficult and knotty question for which there is no single answer. Its solution is essential to the success of industry training programs and is the joint responsibility of management, labor unions and educators.

C. D. Dosker (Gamble Brothers): The question posed by Mr. Norton does present some complications in some plants that are unionized. In most cases, however, management in its dealings with the union can overcome this problem. It becomes serious only when college students are taken as a replacement for union membership, resulting in layoffs in order to take on students. Wise management will not let this happen. While it is not possible in all plants, many plants and most unions recognize the value of training programs of this kind.

Mr. X: How much attention do prospective employers give to grades or scholastic records when considering employment of college graduates?

Dr. Kaufert: Except in cases where employers want men for special research assignments, they pay relatively little attention to grades or scholastic record. They are, and I believe they should be, more interested in a graduate's personality, cooperativeness, willingness to work, enthusiasm, and other personal qualifications. However, I would qualify my answer to say that prospective employers certainly are interested in knowing that a student has done average or better than average work in his courses.

Mr. Crawford: We always try to hire men with high scholastic averages, as they must compete with the same men in business that he has been competing with in college. There is no substitute for the ability to think, which is expressed in scholastic records.

Mr. X: Is it possible to develop more of the industry sponsored factory-classroom training programs such as the one conducted by the University of Michigan in cooperation with Grand Rapids furniture industries?

Dr. Kaufert: Added programs of this nature in several other fields of wood utilization are in the process of being developed at other universities. With both the universities and industries interested in developing this type of program, progress should be much more rapid in the future.

Mr. Dosker: I believe it is definitely possible to develop closer cooperation between educational institutions and industry in cooperative training effort. The work done by the University of Michigan is outstanding in this connection. I believe such a program could be accomplished, especially where the forestry schools are within reasonable distance of wood-using industries. Such industrial contact on the part of the student is bound to produce greater interest in his work.

Mr. X: Should basic course work in the biological, natural, and social sciences be reduced and a greater amount of time be devoted to applied courses?

Dr. Kaufert: In my opinion we should not reduce the basic science and social science courses in order to make room for more applied courses. To do so tends to make university training programs similar to those of vocational schools. We should strengthen our basic course program and not weaken it.

A. J. Panshin (Michigan State College): It depends on what is meant by applied courses. No work in biology and in physical and social sciences should be sacrificed in favor of applied courses of a vocational nature. If, on the other hand, by applied courses is implied training in engineering on the college level, such courses should be given proper emphasis along with the basic sciences, if well rounded technical training in the field of wood technology is to be achieved.

Graduate Training in Forest Products Technology

E. S. HARRAR, *School of Forestry, Duke University*

The training of forest products technologists is no longer a minor by-product of professional forestry training. The recognition of this fact suggests expansion and improvement in the technologist's training to prepare him better for his ultimate employment. The master's degree and the doctorate each has its own value for fitting young men for professional work in the forest products industries. A serious lack is industry-sponsored fellowships and assistantships on a scale common in other industries.

Introduction

ONE cannot discuss graduate training in forest products technology without first evaluating the existing undergraduate curricula in this field, for it is here that the foundations are laid upon which advanced study and research are anchored.

It is only natural that instruction in wood technology and wood utilization should have had its inception in the schools of forestry. Initially, such studies enjoyed only a minor position in the curriculum and were incidental to the primary task at hand—that of training professional foresters. Rapid technological advancements in the harvesting, seasoning, and conversion of wood into a host of saleable commodities, during the past two decades, gave material impetus to the creation of new and the expansion of existing curricula in forest products technology. With but few notable exceptions, however, these foster children of the professional forestry schools are still encumbered with many of the disciplines of production forestry non-essential to the training of men for employment in technical phases of the wood-working industries.

That the training of forest products technologists is a distinct and separate endeavor, and one no longer tied to the apron strings of professional training in forestry, is now readily acknowledged by no less an authoritative body than the Society of American Foresters. By enforcement of its recently adopted by-law 5, membership into this Society is denied to all graduates in forest products curricula from no less than 12 of the 23 accredited schools. Many have viewed this sudden turn of events with alarm because its impact has not been as yet fully realized. Is this not real recognition of the place of forest products technology training in our schools? Have not the schools been given freedom of action to reevaluate, strengthen and replace non-essentials with needed fundamentals in the undergraduate forest products technology curricula? If the answer to both of the questions is in the affirmative, then careful consideration should be given to the quantitative needs for, and inclusion of advanced instruction in mathematics, chemistry, and physics, selected courses in mechanical and industrial engineering, electronics, time and motion studies and technical writing. A curriculum embracing disciplines such as these, carefully integrated with sound training in the technical properties of wood and their industrial applications, would result in the production of men much better prepared for industrial employment. Such an undergraduate program would also provide a solid foundation from which to launch graduate training in specialized and highly technical phases of forest products technology.

Values of Graduate Training

Graduate training in forest products technology has two principal objectives. The first of these is to grant qualified college graduates of high scholastic achievement an opportunity to pursue coordinated and carefully planned programs of advanced study directed toward specialized fields of interest. The second is to foster and promote research, both in the pure and applied aspects of the science.

The values to be derived from graduate study are by no means restricted to the assimilation of knowledge. Unfortunately, however, other aspects of such training are somewhat intangible, and do not appear on the students' transcripts of record. Thus, only too often, they are neither recognized nor their importance fully appreciated.

The graduate student, unlike the undergraduate who is carefully nurtured through four years of prescribed course work, spends an ever increasing amount of his time working independently of others. He is encouraged in logical and creative thinking, and while he is frequently councilled, he must develop initiative and resourcefulness. In fact, his success or failure in graduate pursuits is largely dependent upon his personal achievements, and the judgment he exhibits in the planning, development, and execution of his work.

An all too common criticism leveled at today's college and university graduates, and particularly at those engaged in technical endeavors, is that of their inability to write even the simplest of reports. It is a sad commentary, yet no less valid, that many undergraduates have never been made to understand or to appreciate fully the necessity for mastering the

rudiments of good English composition. In most graduate training programs in forest products technology, the student is required to submit a thesis prepared by himself and based upon some original study or piece of research. In the fulfillment of this requirement he is trained in the orderly procedures of amassing, analysing, interpreting, and evaluating data. But what may be of equal importance, during the preparation of the manuscript he is not only schooled in logical and interrogative thinking, but impressed with the necessity for clarity and preciseness of expression, technical accuracy of description, and proper sequential arrangement of the material presented. While the completed thesis itself may represent only a minor contribution to knowledge, a not too uncommon feature of master's theses, the experience gained in being made to report the results of his efforts in a style and form acceptable for publication, will prove of immeasurable value to him in his professional career.

Forums and seminars are common and useful tools in graduate training. Active participation in functions of this sort materially aids a student in overcoming his timidity in appearing before an audience. In making several such appearances during his period of training, he develops poise, self-assurance, and a modicum of speaking ability.

Upon the successful completion of his graduate studies, the student is ordinarily qualified to enter into a somewhat more advanced level of employment above that normally available to those holding only a baccalaureate degree. Experience has revealed that he is also better prepared to accept responsibilities entrusted to him and to execute his duties with a high degree of proficiency.

Training at the Master's Degree Level

The programs of study offered by 16 of our schools of forestry leading to a master's degree in forest products technology are nigh indefinable. They run the gamut from what may well be described as a post-graduate-in-course program covering a wide selection of subjects, but in which no thesis and a minimum of laboratory work is required, to one that is highly specialized in a narrow sphere of interest and in which the major emphasis is placed on research. This situation is by no means peculiar to forest products technology training, however, but occurs quite universally in several other fields of endeavor. The desirable balance between advanced course work and research in forest products technology training at the master's level has never been defined, nor probably can it be. Laboratory facilities, library, available equipment, the nature and quality of work offered by supporting departments of the parent institution, and limitations of the teaching staff in time, numbers, and experience, logically dictate the sort and kind of programs that may be reasonably offered within any one school.

In its modern dress, the master's degree, even in the natural and physical sciences, fundamentally is not a research degree. Rather it connotes advanced study in a narrow or specialized sphere of learning, and represents a level of scholarly or professional attainment. It is this writer's firm conviction, however, that because of the training and disciplines involved, basic aspects of research should be emphasized, and the preparation of a thesis, even if based on the results of but a small independent study, should be a universal requirement for all students pursuing work in forest products technology leading to the attainment of the master's degree. Moreover, laboratory and field work should also have a dominant position in such programs in order that theory may be correlated with application wherever and whenever possible.

Summarily, graduate training at the master's level may well serve both as a foundation and a stepping stone for study leading to the doctorate. In the administration of such programs, however, the principal objective should be that of training men for technical careers in the woodworking industries, and to prepare them to meet more completely and efficiently the demands made of them in the daily performance of their responsibilities, be they in production, procurement, sales and service, quality control, research and development, or in other assignments.

The Doctorate in Forest Products Technology

The doctorate is essentially a research degree. It is not based upon the completion of a prescribed period of study involving numerous highly specialized courses, but rather upon evidence of high scholastic achievement in a special field of knowledge and the production of a scholarly dissertation embodying the results of original research.

Graduate training leading to the doctorate with a major in one of the more highly scientific aspects of forest products technology is offered by six of the nation's schools of forestry. Candidates for this sort of training are not numerous. Those completing their programs of study have found gainful positions with federal, state and private research and development laboratories, experiment stations, the pulp and paper, wood preservation, synthetic fiber and plastics industries, and in combined programs of teaching and research at the college level. On the other hand, within the industries using wood *per se*, there has been little or no effort on the part of management to bring into the organization experienced and thoroughly trained men with product and process research as their objective.

Research

Each year the automotive, meatpacking, ceramic, pharmaceutical, chemical, electrical and electronic, and the light and heavy metals industries, to mention but a few, provide many thousands of dollars

for subsidizing pure and applied research in the American colleges and universities. These funds are usually allotted in the form of scholarships, fellowships, research assistantships, and even post-doctorate grants, and commonly include liberal contingents to cover incidental expenses.

The recipients of these awards, graduate students of proven scholastic ability, are selected on a competitive basis. Under the guidance of experienced and qualified leadership, they are expected to devote a portion of their program to the pursuit and execution of a research project in the sponsor's field, the results of which may be embodied in a thesis or dissertation and submitted to a faculty in partial fulfillment of the requirements for a degree. In numerous instances, funds of this sort are provided for specific projects, while in other cases only the general field of study is stipulated, the actual selection of a problem being left to the discretion of an advisory committee.

But let it not be said that the disbursement of moneys such as these represents a generous philanthropic gesture. Rather it is full recognition of the utility of research as a tool in product and process development and a modest investment in cash which is often returned ten-fold.

In view of the experiences of these industries, and their recognition of the returns to be derived from diverting a small part of income to the promotion of research, it is difficult to account for the apparent apathy on the part of most wood using industries to habilitate similar programs, geared to their respective needs. Perhaps management is laboring under the misapprehension that the training of professional foresters is still the principal occupation of forestry schools. If so, then we have been most dilatory in making it generally known to industry, that today, instruction and research in forest products technology at the graduate level constitutes a major field of specialization in the curricula in many of our institutions.

The creation of a substantial number of fellowships and research assistantships by the forest products industries would serve several useful purposes. First, it would furnish an incentive for capable young men, who might otherwise be directed into other channels of learning, to pursue graduate training with the view toward a technical or administrative career in industry. Second, it would assure a small but steady output of technically trained men, many of them of potential management calibre. Third, it would provide an inexpensive means for inaugurating research projects of either short or long duration which, within an organization, would be incapable of initiation because of inadequate research facilities and manpower requirements. And finally, it would make for closer liaison between the industries and the schools. A more sympathetic understanding of each others problems would be effected, and in turn reflected in the trainees' better appreciation of industrial problems, needs, attitudes, and points-of-view.

Discussion

Thomas D. Perry (Engineer): Is there a swing from technical to non-technical employees in wood-using industries, and are colleges leaning to trade schools?

Mr. Harrar: Our School of Forestry operates only at the graduate level, and Duke accepts students from liberal arts and technical schools. Liberal arts students of broad interest often progress most rapidly because of their training in the basic sciences. The teachers' job is to teach men to teach themselves, but without a good sound training in fundamentals, the capacity of a student to handle advanced study is limited. It is my personal opinion that there is a minimum of "trade school courses" in the curricula, and that there is no tendency to increase them.

Frederick F. Wangaard (Yale University): I haven't found any marked difference in the advancement of technical and non-technical students.

A. J. Panshin (Michigan State College): It is happening but it doesn't have to. Michigan State is trying to adjust curricula to the needs of industry and provides time for East Lansing, Michigan, electives.

What Does the Forest Products Industry Expect from College-Trained Men?

GEO. L. DRAKE, *Administrative Vice President, Simpson Logging Company, Shelton, Washington*

The practical approach to this question, it seems to me, is first to set forth what the forest products industry expects of the young college graduate and then to point out how the schools can attempt to meet these expectations, and send out graduates prepared to fill the needs of industry.

The following are essential for the success of the college graduate in the forest products industry: 1. To be practical. 2. To have an interest in a future for private industry. 3. To have ability to get along with people. 4. To have ability to express ideas clearly. 5. To have ability to analyze a problem and to know where to find the answer. 6. To have a sound foundation of physical laws and the fundamental nature of wood. 7. To have a sound knowledge of cost control and statistics.

THIS doesn't read much like the average college curriculum, but I will attempt to explain the importance of these points and how, in the judgment of many of us in the industry, they affect the future of the graduate.

1. To Be Practical

The forest products industry, as it exists today, has evolved over a period of many years. This evolution has developed a practical way to manufacture many useful items of commerce. Wood is a complex material, and present methods for its use seem at times outdated; yet careful investigation almost always shows factors which indicate the method to be a desirable one. The forest products industry is one where a little knowledge could be dangerous, whether in research, production, or sales. Practical experience is a necessary adjunct to "book larnin", and it is hard to determine where to place the emphasis.

Young men preparing for the forest products industry should get the maximum of practical experience during their college years. They should look for jobs where they will work with tools and with men. Fire lookout jobs may be fine for a week or two but they certainly do not give opportunity for as much practical experience as work in a plant or in a laboratory. There is always the temptation to seek the job which offers the most money, rather than the one with less pay but with more opportunity for practical experience which might be helpful towards the life work chosen; but it is wiser to sacrifice these few extra dollars at the outset and keep in mind the greater gains in the future. It is this practical experience which prospective employers check into when considering men for a job.

It would be well for the schools to impress on their students the value of practical experience. The dean, or someone he may delegate, should make it a point to get close to these young men and try to guide them along right lines of thinking. In this connection I feel that one of the problems of our schools in training men for the forest products industry is to get men on the faculty who have a background of practical experience. There is no substitute for it. The soundness of teaching and the help that can be given to students depend to some extent on the practical backgrounds of the faculty.

A serious need exists for more men trained specifically for the forest products industry. The industry is becoming more complex and will continue to do so. This requires technically trained men to fill positions of responsibility. At present, most of the needs of industry are being filled by chemists and various categories of engineers, rather than by men trained specifically for the field. Until the educational institutions recognize the need for people trained in this field, the industry will have to carry a part of the educational load.

2. Interest in a Future for Private Industry

This point may seem far off the beam and probably would have been twenty years ago. But with the many philosophies floating around today, industry is definitely interested in this point. A man who believes that all industry should be owned or controlled by the government is not going to have his heart in the job. He must realize that the only way private industry lives is by having a favorable balance sheet, since industry cannot depend upon the taxpayers to make up deficits. When a man appears to be more interested in when his "social security" starts than in the work he is to do, we lose interest in him fast. We are more interested in the man who is thinking of the possibilities of the future and who realizes that his own future is more or less what he himself makes it.

3. Ability to Get Along With People

It may sound afield to list as a qualification this elemental point, as everybody realizes it is nice to have the ability of getting along with people—even with your wife or secretary. The reason I am listing this as an essential point is that no other industry

depends more on the good will of the people it lives and works with. All the fine plans of long-time forest management, on which the end forest products industry depends, can be weakened through poor public relations in the local area. All our resources lie out-of-doors in plain sight of the public, including the assessor; and since the settlement of America, forest lands have been looked on as the sportsmen's hunting ground. And today we have the recreationist equally interested in our lands. For that reason it is essential that the men close to the public, such as a forester for instance, must be able to make friends rather than enemies.

Furthermore, inasmuch as the young graduate is more or less on trial by his employers and fellow workmen in many places, whether he is the type men like to work with or for, will have considerable effect on his success and his worth to the company. True, there may be some jobs where the man works by himself, but in the main he is going to be thrown with other people; and to enjoy other human beings is a distinct advantage.

4. Ability to Express Ideas Clearly

It is recognized that this is an important factor in many lines of business, but it is particularly true in the forest products profession. The forest products industry is a complex one and business organizations are generally large. Top management cannot personally obtain all its information but has to depend on the reports of others. Many times it is the job of the graduate to make these reports. If they are accurate, thorough and clear-cut, they will be of the utmost value to the head office. If the man does a sloppy job, little confidence will develop in his work. The same holds true of the day-by-day accounts of his work.

We old-timers feel there has been a letting down in emphasis on seeing that men learn to express themselves clearly and to write good reports before they leave our colleges. We feel there should be a return to the early rule of "unity, coherence and emphasis" as the basis of good English. And it might be a good idea to add a course in report writing to the curriculum. If this sounds trivial, sit in any executive's chair and read the poorly thought-out reports that come from college men, and see the time and effort it takes to get them to bring out all the necessary facts clearly.

5. Ability to Analyze a Problem and Know Where to Find Answers

No one expects the young college graduate to know the answer to every problem which arises, but he should be able to define what the problem is and know where he can find the material to supply the answer.

Ability to solve problems depends to some extent on the type of training given in school. If the individual has merely listened to lectures and has had reference books to read, without finding out "why is this so", he will be handicapped when faced with actual problems. The man who has formed the habit of inquiring into things is the one we are looking for. In this day of radio and television there is too much tendency to be satisfied with superficial knowledge gained visually or from hearing—probably aided by "singing commercials"—and not enough real studying.

Along with books of standard tables, etc. there is an increasing volume of literature on various phases of the lumber industry, and such outside reading is of definite value. We in the industry get many ideas from our trade journals.

You may think that I have gone a long way from the subject assigned me. It is true, but I do feel deeply that these things have much to do with the success or failure of the young graduate, at least during the formative years of his employment. Some of these seemingly trivial things can put him behind the eight-ball, and it means special effort on the part of his employer if he is to be straightened out. Employers are busy men who have other jobs to do. Industry feels that it lies within the power of the school faculty to see that a young man gets the proper slant on these points which may prove as important as some particular phase of his technical education.

6. A Sound Foundation of Physical Laws and the Fundamental Nature of Wood

The major emphasis in forest products education should be placed on a firm foundation of general knowledge. The tendency to narrow fields of specialization is deplorable. The rapid expansion of the industry into many new fields, many of them without any available knowledge or previous experience, should readily point out the fallacies of a narrow specialized education. Industry needs men with vision which is backed up with a good allround knowledge of wood. Obviously our problems in the Douglas fir region are vastly different than those of other areas—yet must depend upon the same educational sources for our men. The ability to think logically is mandatory and can best be instilled in the student by a general technical course rather than a highly specialized one.

7. Knowledge of Cost Control and Statistics

"Cost figures are a sharp-edged tool that may be used for many purposes. In the final analysis they reveal whether or not one is doing the job efficiently." Business is carried on to make money and the work done by the graduate will ultimately be judged upon an economic basis.

Consequently, industry looks with favor on the introduction of cost accounting courses in our colleges. Recognized methods of specialized accounting as well as general business accounting are being

developed, and the man with a good understanding of this subject is far better equipped than we old-timers who did not have this advantage.

Wood involves statistical work. This is true whether in connection with living trees or the products made from them. A good knowledge of statistical methods is very desirable, as we have found it the only practical solution to many problems in the industry. In research, for example, it is sometimes the only method available for setting up experiments and analyzing data. The forestry schools have recognized the usefulness of this very versatile tool, but unfortunately our other technical courses have not. Statistical methods make simple so many complex problems that their importance cannot be overemphasized.

If these courses are not required, they should certainly be recommended to all men preparing for private industry—regardless of the line of work a man takes up, they will stand him in good stead.

The colleges can better prepare their graduates for work in private industry or for any other life work their men may take up if in addition to their technical training they emphasze the fact that technical knowledge alone is not the sole key to success, but that with it must go the age-old virtues which can be summed up as common sense and faith in your fellow man.

Discussion

Mr. X: Why is it essential that a man be able to analyze a problem or to know where to find the answer?

Mr. Drake: The type of men being discussed is that to which the industry looks for future leadership. If these men aren't able to clearly analyze the problems that will confront them and know where to get sound knowledge in solving them, they aren't the type industry is looking for.

Mr. X: You have listed seven essential requirements that you feel college men entering the forest products industry should have to make a success of their lifework. How do you feel the colleges can help?

Mr. Drake: In my paper I attempted to point out seven essential requirements, and where the colleges could help. I feel confident that ways can be found by the schools to encourage men along the lines suggested if the school faculty recognizes that these factors are just as important as a knowledge of silviculture or botany.

Mr. X: You speak of the need of their men obtaining practical experience during their school years. Is industry willing to give them a chance to gain this experience?

Mr. Drake: Book learning without practical experience is not as valuable to the student as to see how theory ties in with practice. Every man taking a technical course should endeavor to get experience during his college vacations in lines of work as close as possible to that in which he is specializing.

Even if the particular job a man would like is not available, there are other jobs which will give him some degree of experience. For example, he may want to be a logging engineer and cannot find work with a logging firm during his vacation. He might be able to get a job on a road construction project in his home township and thus get some practical experience.

Mr. X: Why do you stress the need for these men to be sympathetic to the principle of private enterprise?

Mr. Drake: Today industry is under attack by many who are not sympathetic to the principles of private enterprise, and if a college graduate enters private enterprise antagonistic to the system under which he is to work, he certainly is not an asset to his employer.

Mr. X: Why is it essential that a man have the ability to express ideas clearly?

Mr. Drake: The only way a person can convey to another what he knows of a certain subject or problem is either vocally or in writing, and the clearer he can put over his ideas in language that is easily understood, the better he can sell himself. What I was trying to put over to these college boys was the need of expressing themselves in clear English, a subject being given too little consideration in their college work.

E. Sigurd Johnson (N. C. State College): Do you feel that there is a place in technical education for two types of curricula, broad technical background courses to create an understanding of wood as a raw material, and technical courses specifically designed for a particular industry such as furniture manufacture.

Mr. Drake: I feel that technical training should be supplemented by English, public speaking, how to get along with people, and other broad subjects. Schools need more emphasis on general principles that are fundamental rather than trying to solve problems that are peculiar to an individual company.

Industrial Orientation and On-The-Job Training Program for Technical Employees

G. MAURICE HILL, *Manager of Production, Drexel Furniture Company, Drexel, North Carolina*

A considered and carefully organized plan is set forth for the orientation and training of new employees, for the training of supervisory employees in line with modern responsibilities, and for the training of future management.

Introduction

FIVE years ago the Drexel Furniture Company went through a major reorganization with major changes in top administrative personnel. This change came just prior to the end of World War II. At that time the staff had been heavily depleted by the needs of the Armed Forces and by loss of personnel to defense plants. While this situation was far from ideal, it did give the new management an opportunity to look at its organization in long range perspective and to plan to rebuild the organization on an effective basis with proper regard for the basic principles of good business and industrial organization, and the latest developments in this field.

In making this survey we came to some definite conclusions, which have been the basis for much of our thinking in our attempt to build an organization, and to develop a permanent plan for the orientation and training of our present staff, as well as new employees. While our conclusions will undoubtedly be subjected to debate and differences of opinion by other members of our own industry, as well as related industries, they must be stated, in order to fully understand the development of our own training program and the significance of its principal objectives.

At the end of our survey, we found ourselves with the opinion that the furniture industry was at least a full generation behind industrial development and organization in such fields as metal working, textiles, chemicals, electrical appliances and other related industries. Plants, as a whole, were directed and staffed by men who had grown up in the industry, with few individuals who had been specially trained in this field, and an increasingly small number of individuals who had had technical training in related fields. While this situation is changing, it still exists today in the majority of cases.

In order to meet this problem, we have developed a training program with the following broad objectives:

I. Training of our present supervisory staff.
II. Orientation of new employees and training of workers with technical skills.
III. Training of a future management group.

Training of Present Supervisory Staff

An analysis of our supervisory personnel, including all those men at the foremen level, as well as those above this level, revealed that the majority of all these people had little or no formal technical training. As a matter of fact, the majority of them had less than a high school education, and without the benefit of any training program. Prior to this time most of them had little conception of the problems of a foreman or superintendent under present conditions. The situation may well be described by this quotation from a recent talk made by Mr. M. J. Rathbone, President of the Standard Oil Company of New Jersey, who said:

> "The old well-known responsibilities of a foreman for safety, quality, quantity, cost, etc. are not enough. Today's foreman must know company policies and public relations. They must be familiar with labor techniques, national labor trends, sociological trends, and many other similar matters. Technological developments demand that foremen be more broadly educated. The complexities of most modern business demand that foremen know the inter-relationship of the various departmental functions and how their reactions may affect other departments. They must know and observe many government regulations and requirements. The only way a foreman can become efficient and expert in all these lines is through comprehensive, well-planned training programs. Every progressive business should train its foremen and not let them "just grow like Topsy." You would not expect an engineer or doctor to perform his work without the proper training. How can we expect our foremen who are production men, our labor handling men, our public relations men to do their jobs efficiently without proper training?"

A recent survey, conducted by an independent research organization, among top management and foremen alike, showed that 78 percent of a foreman's time and skill has to do with handling his personnel, and that only about 22 percent of his time and skill is spent on the technical aspects of his job. The breakdown was as follows: Being a good manager and planner, 26 percent; Handling people, 28 percent; Explaining policies and procedures, 24 percent; Applying technical knowledge, 22 percent.

Whether we agree with the facts revealed by this survey or not, everyone will agree, after thinking the matter over, that more time is spent by the supervisor in directing his work force than is spent on the technical aspects of his job. A great portion of American industry has recognized that an individual must learn the technical aspects of his job through years of experience and training before he can be given responsibilities. Yet, in most cases industry has made supervisors out of these technicians with-

out giving them the training necessary to meet the new responsibilities they face as supervisors. A supervisor needs technical skill, *plus* knowledge of his authorities, skill in instructing, skill in planning, and skill in handling people.

Our first step, therefore, was to organize this group into a planning group with definite and regular meetings, in which they would be concerned first, with learning more about the problem of directing people and coordinating the activities of their department with other departments; and second, with the technical skills and knowledge necessary in their own particular fields.

The following outline is a concise summary of the plan for the operation of this phase of our training program:

Supervisory Training

I. Management Skills

A. *Operation of the Course*

1. *Groups*
   (a) All foremen in each plant meeting together. (b) Foremen of all plants meeting together on such special occasions as "Foremen's Day."
2. *Meeting Times*
   (a) Once each month except during summer months. (b) Dinner meeting at time most suitable for each plant. (c) Meetings to be held at most appropriate place.
3. *Method of conduct*
   (a) Chairman—Plant manager or plant personnel manager. (b) Discussion, lecture, or both.
4. *Mechanics*
   (a) Invitations to each meeting accompanied by outline of topics for discussion. (b) Use of charts, graphs, models, etc. where possible. (c) Detailed write-up to members at conclusion of sessions.

B. *Suggested Topics*

1. *Personnel Practice and Policies*
   (a) Discussion of present labor conditions, labor turn-over reports, absenteeism, etc. (b) A study of company personnel policies and consideration of possible improvements. (c) Discussion of employee benefit plans, such as group insurance, hospital insurance, social security, Workmen's Compensation, Unemployment Compensation.
2. *The Job of Being a Supervisor*
   (a) The obligation and privileges of being a supervisor discussed as follows:
   (1) What the supervisor expects. (2) What management expects. (3) What workers expect. (4) The privileges of supervision.
3. *Training—A Supervisor's Responsibility*
   (a) A discussion of the importance of proper instruction of workers in "how" to do their jobs.
   A four-step plan aimed at aiding the supervisor in getting the worker to do his job correctly, quickly, and conscientiously by:
   (1) Recognizing training needs. (2) Planning and organizing job training. (3) Supervising job training. (4) Job instruction procedures.
   "If the worker hasn't learned, the instructor hasn't taught."
4. *Planning Work and Budgeting Time*
   (a) A session which deals with the importance of "planning or thinking ahead."
   (1) Steps in improving a job.
   a. Analyzing present methods. b. Visualizing new and improved ways of doing a job. c. Accepting suggestions for better methods.
5. *Effective Discipline*
   (a) A consideration of the supervisors' responsibility for maintaining effective discipline, with emphasis given to preventive rather than punitive discipline.
6. *Cost Control and Waste Elimination*
   (a) Need for cost control. (b) Methods of cost control. (c) The supervisor's part in cost control.
7. *Our Industrial System*
   (a) The development of the industrial system in America. (b) The organization and financing of a corporation—the obtaining of capital and the relationship of stockholders. (c) The relationship of wages, prices, and profits.
8. *Labor—Management Relationships*
   (a) History of the American Industrial System.
   (b) The growth and development of labor unions.
   (c) Labor Laws.
   (1) National Labor Relations Act. (2) Fair Labor Standards Act. (3) Walsh–Healey Act. (4) Fair Employment Practices Act. (5) State Labor Laws.
9. *Work Simplification*
   (a) A program conducted by some specialist in "Work Simplification and Motion Economy."

II. Technical Skills

A. *Purpose*
To give foremen the opportunity of improving their knowledge of the various technical phases necessary for the efficient management of their departments.

B. *Operation of the Course*

1. *Groups*
   (a) Foremen by departments; that is, all rough machine foremen meeting together, all finish machine foremen, all cabinet foremen,

etc. (b) Occasional meetings of all foremen in a plant, and all foremen in the company when the subject is of common interest.

2. *Meeting times*
(a) One meeting each week until all departments have at least one meeting each spring and each fall. (b) The meetings shall begin at 3:00 p. m. and adjourn not later than 5:00 p. m. with dinner following. (c) Place of meeting—to be worked out for convenience.
3. *Method of Conduct*
(a) Chairman of meeting—Personnel Director. (b) Discussion, lecture or both by plant manager, superintendents, foremen or other qualified person.
4. *Mechanics*
(a) Invitations to each meeting accompanied by outline of topics for discussion. (b) Use of charts, graphs, models, etc. where possible. (c) Detailed write-up to members at conclusion of sessions.

C. *Suggested Topics*
1. *Yard Group*
Subjects for discussion. (To be developed.)
2. *Rough Machine Group*—Subjects for discussion
(a) Lumber Grades, yield, waste, labor. (b) Automatic cut-off saws vs. swing saws. (c) Do conveyors save labor and speed production? (d) Glue jointers, vs. straight line ripsaws. (e) How much attention can you give to utilizing scraps and not allow labor to wipe out the savings? (f) Gluing cores . . . glue reels vs. steam heated presses vs. electronic presses. Which is better in regard to efficiency, quality and working conditions. (g) How long should cores be conditioned before planing? Before veneering? Under what conditions—such as temperature, moisture content, circulating air, etc.? Should cores have sticks between them while in the hot box? (h) Should moulders be located in rough machine, or finish machine department? (i) Discussion on glues—animal vs. resin. (j) Best method of ripping—parallel or wedge ripping?
3. *Finish Machine Group—Subjects for Discuscussion*
(a) Discusion of forms and patterns for shapers and routers . . . metal lined and wood forms. (b) Metal patterns for bandsaw. joints, variety saw, double end mitre saws and joints, variety saw, double and mitre saws and tenon machine . . . difference in speed, quality of work and labor. (d) Dowelled joints vs. spline vs. mortise joint. (e) Electronic presses vs. air presses for frames and banding tops. (f) Is hand sanding necessary after Nash sanding on turned post? (g) Discussion of tenon operations to eliminate hand work on slower machines, such as variety saws, shapers or routers. (h) Which is better for light shaping, a detail shaper or router. (i) Which is better—to have a skilled man to operate each machine, or have a sub-foreman or key man in charge of several machines with non-skilled operators.
4. through 10. Finishing, Rubbing, Shipping, Carving, Veneer, and Inspection Groups. Subjects for discussion to be developed.

Orientation of New Employees and Training of Workers With Technical Skills

In approaching the problem of training the individual workman or mechanic, we have again come to believe that it is important for every man in the organization to know something of the policies and overall operations of the company for which he works, in order to do a satisfactory job at his individual post. After this orientation is completed, it is then necessary to take up the problem of special training for those employees with technical skills, which must be adapted or further developed to fit our particular needs.

We have, therefore, developed a training program, which provides each new employee with a brief, but nevertheless thorough orientation period, in which all phases of the company's policies, planning and objectives are laid before him, with particular regard for those which will affect him as an individual. The *first phase* of this program is outlined in detail as follows: (1) Brief outline of the history of the company. (2) Discussion of the organization chart, showing company management and major divisions and discussion of the functions of each division. (3) Discussion of employee benefits. (4) Outline of company personnel policies, including rules and regulations for employees. (5) Discussion of products manufactured by the Company from the customer's viewpoint, with emphasis on the significance of sales, promotion and advertising in providing steady employment. (6) The role of the individual employee in furthering the interest of the company, as well as his own personal welfare.

In the *second phase* of our program of training workers with technical skills, we have found it extremely difficult to approach this matter in a formal manner, except through the time-honored relationship between the foremen and employees, who give him as much individual time and attention as possible.

While we intend to develop a formal training program for such employees, it is our present policy to delay the development of this phase of our program until we have more fully developed the program of supervisory training and have the capacity in this group to direct and coordinate this phase of the work. This policy applies only to factory workmen and mechanics, and not to technical employees of higher calibre and those in key positions. These will be treated separately in the paragraph below.

Training of a Future Management Group

The management of our company feels that the woodworking industry in general, and the furniture industry in particular is at the threshold of a new era of industrial development, with primary emphasis to be placed first, on modern management methods, and second, on new technical skills and machinery.

It is, therefore, imperative that new employees with specialized training be brought into the organization, in order to develop a reservoir from which to draw the future key employees and executives of the company. This is obviously a long range program and one which must be approached with the utmost care, if we are to avoid the disruption of our present staff, the creation of dissatisfaction among employees who grew up in the industry, and the normal and natural resistance on the part of present employees to new employees with special training.

While we have already employed and have molded into our organization a considerable number of individuals with specialized training during the past five years, we now feel that a formal training program is necessary for this purpose. The plan which we have developed is outlined in summary form as follows:

Junior Management Clinics

A. *Purpose:* To develop basic management skills; to acquaint new members with the structure, functions, and problems of the Drexel Furniture Company; and to implement the technical knowledge being gained by "on-the-job" training.

B. *Operation of the Course*

1. *Meeting Times*
   (a) Once each week for 8 weeks in spring and fall (b) Meetings to be held at the main office in Drexel. (c) Meetings to begin after working hours at time most suitable to group.
2. *Method of conduct*
   (a) Lecture by key personnel responsible for each function (one-half hour). (b) Discussion—not to exceed one-half hour. (c) Chairman of meeting—personnel director or assistant assigned by the Director.
3. *Mechanics*
   (a) Invitations to each meeting accompanied by outline of topics for discussion. (b) Eligibility—junior management trainees. (c) Use of charts and graphs where appropriate. (d) Detailed write-up to members at conclusion of sessions. (e) Certificate of successful completion following last meeting with dinner and address by the President on Management Objectives.
4. *Supplemental Work*
   (a) Establish a technical library to be used by trainees to supplement other training. (b) Occasional special assignments using text books as references.

C. *Topics*

1. *The Furniture Industry*—History, organization, geographical centers, peculiarities.
2. *The Drexel Furniture Company*—History, units, operations, management structures.
3. *Sales*—Place in industry, competition, organization, quality.
4. *The Furniture Market*—Functions, Drexel participation, problems, evaluation.
5. *Customer relations*—Advertising, selling aids, promotions.
6. *Design*—Types of furniture, style changes, samples, development for production.
7. *Production Management*—Functions, organization, integration, problems.
8. *Production Control*—Planning, scheduling, routing, control.
9. *Costs in Furniture Manufacturing*—Breakdown—general, standards, controls, annual statement.
10. *Personnel Department*—Functions, organization, labor relations, developments.
11. *Wages and Job Evaluation*—Competition, general wage changes, job evaluation, administration.
12. *Research*—Organization, areas, developments, projects.
13. *Waste*—Raw Lumber, drying, cutting, in-process lumber.
14. *Quality*—Standards, employees, vulnerable points, style factors.
15. *Machine and Process Developments*—Glues, conveyors, mechanical equipment, electrical devices.
16. *Materials*—Types, problems concerning materials, change in use, forecast.

On-the-Job-Training

A. *Purpose:* To give trainees technical training in the many phases of furniture manufacturing by working in various departments throughout the company.

B. *Training Schedule:* The training schedule for each trainee will depend upon the individual's previous training. The first or basic phase of training will consist of assignments throughout the various departments in the plants. The second or advanced phase is intended to give more thorough and complete training in the various specialized fields.

Those persons who have aptitude for and desire to go into sales or other departments not commonly regarded as production departments will be given special assignments in the various departments related to sales. At some time during this later period arrangements will be made to place the trainee in a retail store to get sales experience.

In order to provide for the needs of all types of trainees, the schedule as outlined should be adequate for any employee without prior furniture knowledge or experience. The amount of training, starting place, etc., will vary with individuals.

1. *Plant*
   (a) Two months—rough machine, (b) Six months—finish machine, (c) Three months—cabinet, (d) Three months—finishing and rubbing, (e) Three months—shipping, (f) Three months—sample, (g) Three months—research.
2. *Office*
   (a) Three to six months—personnel department,
   (b) Three to six months—production planning department,
   (c) Six to twelve months—sales department,
      (1) Order and Billing
      (2) Advertising
      (3) Interior decorating and show room
3. *Retail Store*
   (a) Six to twelve months on retail floor.

C. *Selection*

1. Utmost care should be exercised in selecting trainees. Careful consideration should be given to presently employed personnel, both in the plant and in the office. Superintendents, plant managers, and department heads should be asked to evaluate their employees with great care and make recommendations as to those worthy of receiving training.
2. In addition to presently employed personnel, new men should, from time to time be enrolled in the training program. All new men should be selected with extreme care and should be selected on the basis of previous training and experience, and the needs of the Company.
3. All persons should be given aptitude tests or any other types of tests which would be useful in determining the course a trainee should pursue.

D. *Length of Training*

1. The length of time required to train each man will vary according to his previous training, ability, aptitude, and objective to which he aspires.
2. Trainees without a background of specialized training in the field in which he wishes to specialize will be given the basic training as outlined in all cases.

E. *Progress Reports*

1. All trainees will be observed carefully and merit-rated by his immediate supervisor and superintendent at the end of each three months for the first twelve months, and at the end of each six months thereafter.
2. The trainee shall be informed of any unsatisfactory rating and given special assignments, if possible, to help him overcome such deficiencies.
3. If at the end of a reasonable time it appears that the trainee does not possess the necessary qualifications to continue his program, he shall be so informed and his training terminated.

Conclusion

In consideration of the above plan it must be remembered that every plan must be tailored to fit the individual company for which it is intended. No training program for one company could be adopted by another company without careful study on the part of those responsible for such a program.

The first and biggest job is to prepare the present organization for the steps which will be taken in the future. In a recent conversation with Mr. Leonard Giles, Personnel Director for the Lincoln Electric Company, Cleveland, Ohio he stated that the largest single problem facing their organization was to get the employees to willingly accept a new idea. This truth is so obvious that it has been adopted by our organization as a basic truth, and no step is taken to initiate a new program without spending the maximum in time and effort to prepare the organization for this step.

During the past five years the Drexel Furniture Company has established a number of new departments, which have been staffed by specialists with training and experience in their individual fields. Among these are a Personnel Department, with responsibility for employee-training; a centralized Purchasing Department, a Production Planning and Engineering Department, a Research Laboratory for applied research as contrasted with pure research; a Sample Plant for the manufacture of all models of products to be manufactured by the company, including the tools, jigs and fixtures, which will be needed by the producing plant; a new Cost System and Standards Department, and a new Advertising Department. These departments have proved invaluable as spots where on-the-job training may be given to new employees.

The entire program of training is under the direction of the Personnel Division, but all department heads and other executives of the company participate in the program as much as possible and wherever they are needed.

Panel Discussion of Forest Products Training and Education

Thomas D. Perry (Engineer): Are colleges leaning to trade schools?

E. S. Harrar (Duke University): Duke accepts students from liberal arts and technical schools. Liberal arts students of broad interest often progress most rapidly.

Frederick F. Wangaard (Yale University): I haven't found any marked difference in progress of technical and non-technical students.

A. J. Panshin (Michigan State College): Undoubtedly there is a tendency in some college curricula to over-emphasize the practical or the trade-school approach to technical training. This stems, in part at least, from an attempt on the part of the colleges to equip their students with enough "practical" ammunition to enable them to secure a first job in industry. But it is due also to the over-emphasis on practical or vocational training by the employers.

It is to be feared that some employers misunderstand the function of college training when they insist on the very narrow, vocational specialization. Probably the crux of the matter is that wood-using industries need two types of technical personnel; the technician for specialized tasks, and the technical personnel, with broad training in the natural, physical and social sciences, from whom future managers and industrial leaders can be selected. The first type should most properly be trained by vocational school or by means of on-the-job training programs. The training of the latter is a college function. Any attempt to combine these two is seldom a complete success, because in four years neither of the objectives can be fully realized.

At Michigan State College an attempt is made to reconcile the two objectives by requiring the students to take a certain number of prescribed courses, two-thirds of which are in the basic sciences, arts and engineering and about one-third in technical work of more specialized nature. In addition, however, the curriculum includes a considerable number of elective credits, which can be earned by students by taking any subjects which they feel will benefit them most in their future professional work. Some practical experience in the chosen field of specialization is obtained through additional requirement of at least 16 weeks of practical work before a man can be recommended for graduation.

James B. Darcy (Pennsylvania State College): Is there value in survey courses in economics, and with the war and a possible compulsory military training, are more than 4 years necessary?

Mr. Panshin: In a four year college program, survey courses are unavoidable. Sometimes this is the only practical means of introducing subjects that serve to broaden the student's understanding of such areas as economics and the business and social sciences. In other words, survey courses serve as a compromise when time for more thorough preparation in some phase of the work is not available, and the alternative would be no exposure whatsoever to subjects of general educational or professional value.

Ed. R. Lynn (Oklahoma A&M College): How much value are field trips to students?

Mr. Panshin: Trips which include several unrelated plants in rapid succession are not very successful. Considerable benefit, however, can be derived if the trips are preceded by adequate discussion of what the students will see on the trip, and the students are later asked for constructive comments on operations they visited, preferably in the form of a written report.

George L. Drake (Simpson Logging Company): Much is to be gained, but brief visits are not much good. Summer work is valuable.

Davis R. Godwin (Atlantic Plywood Corp.): Field trips from N. C. State College to woodworking plants have proved very beneficial to the students. Officials in these plants are very cooperative by answering questions on tours. Tours are conducted step by step enabling the student to grasp the essentials of each operation. If these tours are correctly timed during a course, there is much benefit to be derived from them. Industrial organizations realize that they too benefit from these tours and readily invite both questions and suggestions from the students. The intensive operations of a woodworking plant cannot be learned entirely from a book; therefore, it is my belief that in order for students to get a good idea of different types of operations, field trips are absolutely essential to college training.

E. George Stern (Virginia Polytechnic Institute): Years ago when there was less to be taught, the curricula were not as manifold as today. Instead of a specialized education, a basic education was offered with emphasis on clear thinking and confident self-expression. Both were accomplished to a considerable extent by being taught foreign languages which automatically taught the student to master his native language.

Mr. Drake: Any job will give you a chance to learn if you keep your eyes open. Don't worry about what the job is but take any one to get experience.

E. Sigurd Johnson (North Carolina State College): Furniture plants in southeastern United States can always use students for summer employment. These students are hired at minimum rates but are used as helpers at many different operations and as operators of the simpler machines. Each year at N. C. State College we receive more requests from manufacturers for students than there are students available for this summer work.

TECHNICAL SESSION VII—Thu., May 10, 1951, 9:00 A. M.

General Subject: Utilization and Conversion of Wood and Mill Scrap

Co-Sponsor: American Paper and Pulp Association

Chairman: E. G. Amos—**Recorder:** Louis T. Stevenson

The Manufacture and Utilization of High Quality Chemigroundwood Pulps

P. M. SCHAFFRATH, *Research Associate, State University of New York, College of Forestry, Syracuse, New York*

The economic background leading to the development of the chemigroundwood process is presented as an introduction to a description of the process, the nature of chemigroundwood pulps in relation to normal groundwood, and the general effects of some process variables on the qualities of the resultant pulps. The various economies possible through the use of this process as well as the potential applications of chemigroundwood pulps in various papermaking fields are indicated. Emphasis is placed on conceivable establishment of extended pulpwood supplies through the utilization of hardwood species in areas where the volume of coniferous wood has been depleted.

The Case for Hardwoods as a Pulp Source

THE almost complete dependence of the pulp and paper industry in the United States on wood pulp as a raw material is universally recognized. It is apparent, therefore, that the very life of this important industry in any section of the country is dependent upon adequate supplies of wood suitable for the manufacture of pulps which can subsequently be converted into the wide variety of paper and paper products commonly encountered today. The ever increasing demand for these products is creating an ever growing drain on the forest resources of this country and on those of our Canadian neighbor. In the past, the greatest proportion of the wood pulp was manufactured from the coniferous species, notably spruce and balsam fir. Hardwoods were used to a considerably lesser extent and then primarily in chemical pulping processes where half or more than half of the wood substance is either lost completely or salvaged only in the form of heat from recovery processes. The pulps giving highest yields, mechanical pulps containing nearly all of the original wood constituents, were almost entirely produced from softwoods. In the more recently developed pulp producing areas, good forestry practices have assured a sustained yield in pulpwood operations. However, in the Northeastern United States, the area in which the paper industry of this country first developed, former unscientific forestry practice has changed the forest stand to such an extent that the softwoods, once the predominant species in this region, have been seriously reduced in volume while the volume of the more easily propagated hardwoods has greatly increased.

The growing scarcity of coniferous woods for pulp manufacture, especially in these latter areas, has focused interest on the hardwoods as potential replacements for the diminishing supply of softwoods. In 1948, according to the Department of Commerce, Bureau of Census, the pulp manufacturing industry consumed a total of 21,189,458 cords of wood of which 2,698,542 cords or about 13 percent were hardwoods. Only about 6 percent of these hardwoods (166,149 cords) were used for mechanical pulp production. Mixed northern hardwoods used for groundwood manufacture accounted for only 2,818 cords of this total.

When these statistics are compared with the timber volume in New England and New York, as estimated by Harper[1] in 1945, the need for increased utilization of these species becomes more apparent (Table 1).

TABLE 1.—TIMBER VOLUME[1] IN NEW ENGLAND AND NEW YORK

Status Beginning of 1945

Million Cords

Softwoods		Hardwoods	
Spruce and fir	103	Birch, beech, maple	248
White and Norway pine	40	Oak	30
Hemlock	28	Aspen	17
Other	7	Other	20
Total	178	Total	315

[1]Trees 5 inches diameter breast high and larger; does not include bark. Converting factors: softwood 78 cu. ft. per cord, hardwoods 65 cu. ft. per cord.

Of the total stand, according to this estimate, only 21 percent of the stand consists of spruce and fir while the mixed hardwoods (birch, beech, maple) constitute 50 percent of the total. Even though the drain on these forests from all sources, i.e. the drain for lumber, pulpwood, other forest products, losses from fire, insects and disease, is less than the annual growth (Table 2), the distribution shows that while 42 percent of the drain consists of softwoods, only 35 percent of the growth is represented by these species and only 15 percent of the annual surplus is in coniferous wood.

[1] Harper, V. L., Timber Resources of New England and New York with Reference to Pulpwood Supplies. U.S.D.A., Northeastern Forest Experiment Station, Station Paper No. 5. (1947)

TABLE 2.—COMPARISON OF ANNUAL DRAIN AND GROWTH

Status Beginning of 1945

Thousand Cords

Item	Drain	Growth[1]	Surplus
Softwoods	5,754	6,449	695
Hardwoods	8,040	12,092	4,052
Total	13,794	18,541	4,747

[1]Annual growth of all trees 5 inches diameter breast high and larger including tops and limbs (tops only in softwoods) of saw timber and total volume of trees reaching 5 inches diameter breast high each year. Bark not included.

Genesis of the Process

Due to the great decline in the volume of softwoods in this region, many groundwood mills in the northeast are forced to import coniferous pulpwood from Canada, constituting a costly and economically serious disadvantage for this important industry. It is against this economic background that a group of fourteen farsighted pulp manufacturers in 1946 formed a non-profit corporation named the Empire State Paper Research Associates, Inc., more commonly known as ESPRA, with the stated objective as follows: "To broaden the sources of raw material for the pulp and paper industries of New York State, to increase the fiber yield and papermaking qualities of wood used in the manufacture of pulp and paper, and in general to help improve the economic condition of the pulp and paper industry." The ESPRA organization and the State of New York have co-sponsored the research work carried out at the New York State College of Forestry which led to the development of the chemigroundwood process.

The development and technology of the chemigroundwood process and a large number of supporting data have been published in the technical literature[2] and in the form of a technical bulletin of the New York State College of Forestry[3] by Professors C. E. Libby and F. W. O'Neil, the inventors of the process. It is not the purpose of this paper to repeat this already published and available data but rather to point out, after a brief review of the process itself, the potential utilization of pulps produced in this manner and the economic advantages which may be derived from its application.

Chemigroundwood pulp, by definition, is mechanical or groundwood pulp produced from hardwoods after a preliminary chemical treatment under pressure and temperature conditions which materially modify the physical characteristics of the resultant pulps in relation to groundwood produced from the same species without pretreatment.

[2] Libby, C. E. and O'Neil, F. W., The Manufacture of Chemigroundwood Pulp from Hardwoods, TAPPI, Vol. 33, No. 4. (April 1950)

[3] Libby, C. E. and O'Neil, F. W., The Manufacture of Chemigroundwood Pulp from Hardwoods. Technical Publication No. 72, Bulletin of the New York State College of Forestry. (1950)

Character of the Fiber

Papermaking fibers produced by the chemigroundwood process possess several characteristics which readily distinguish them from those of normal groundwood pulps. While the fibers are still highly lignified, as would be expected from the high yields of pulp (averaging about 85 percent of the raw wood weight) obtained in this process, the character of the fiber is noticeably different. The photomicrographs of typical groundwood and chemigroundwood pulps (Figs. 1–5) graphically illustrate these differences. Spruce mechanical pulp as well as groundwood pulp produced from untreated hardwoods contain large quantities of fine material, broken fibers and numerous undefibered fiber bundles. Chemigroundwood pulps, on the other hand, show a much cleaner fiber, a great reduction in the proportion of fines, and the presence of numerous vessel segments which are almost entirely absent in the pulps produced from untreated wood. Fiber classification tests on the Bauer–McNett classifier bear out these visual observations and demonstrate that pretreatment reduces by more than half the proportion of fibers passing through the 150-mesh screen in this test.

Throughout this work, commercial spruce groundwood pulp has been used as a reference standard for pulp quality, production rates, power requirements and cost comparisons. The use of this standard is justified on the basis that it was originally hoped chemigroundwood pulps from mixed hardwoods would become a substitute for mechanical pulps produced from softwoods. However, the quality of pulps obtained by this process has so far exceeded the original expectations that simple substitution of these pulps for normal groundwood in furnishes has been superseded by their possible substitution, at least in part, for the far more expensive chemical pulps currently in use.

Pretreatment Cycle

The process by which the pulpwood sticks are pretreated for the manufacture of chemigroundwood pulps consists briefly of the following essential steps: (1) pre-evacuation of the charged digester or retort, (2) introduction of the treating liquor without breaking the vacuum, (3) application of hydrostatic pressure and (4) cooking with indirect heat to obtain the desired physical properties in the final pulp. A large amount of fundamental and practical research, employing both small-scale and semi-commercial equipment in the laboratory of the Pulp and Paper Department of the New York State College of Forestry, was carried out to establish these steps in the treating cycle. This research also established the effects of such process variables as treating time, temperature, pressure, and treating liquor composition and concentration on the physical and optical characteristics of the pulps manufactured from the pretreated wood. Numerous semi-commer-

Fig. 1.—Spruce mechanical pulp.

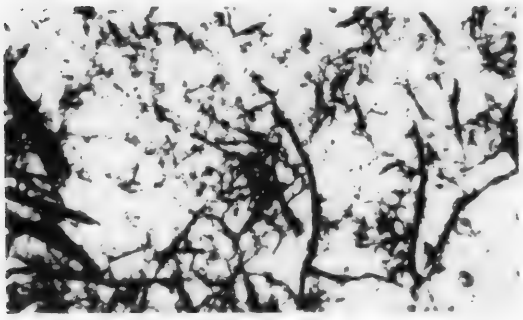

Fig. 2.—Untreated birch mechanical pulp.

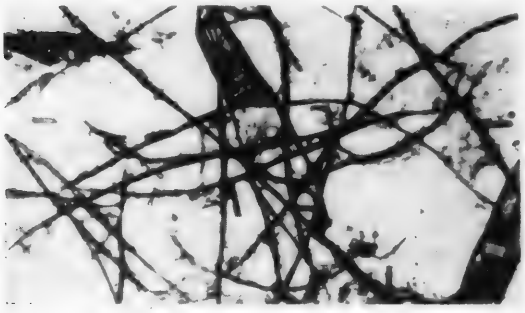

Fig. 3.—Birch chemigroundwood.

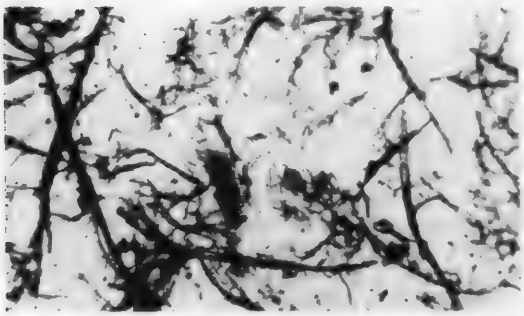

Fig. 4.—Untreated aspen mechanical pulp.

Fig. 5.—Aspen chemigroundwood.

cial runs on the laboratory Great Northern grinder under varying grinding conditions and employing a wide range of pulpstones, have established the great power economy and high production rates characteristic of the chemigroundwood process.

Chemicals

The results obtained in these extensive studies have demonstrated the superiority of sodium bicarbonate buffered sodium sulfite liquors for these pretreatments. Liquor concentrations of from 0.50 to 1.75 pounds per gallon chemical (calculated as sodium carbonate) have been used to produce satisfactory chemigroundwood pulps. The exact concentration of chemical is determined by the wood species, the condition of the wood, the length of the billet, its moisture content and the qualities desired in the final pulp. Treating liquors of this composition have pH values of about 9.0 and have been shown to have little or no corrosive action on normal iron and steel equipment.

Temperatures

Studies of pretreating schedules has indicated that temperature ranges from 120° to 180°C and time cycles of from 4 to 14 hours may successfully be employed, dependent again on the wood used and the pulp qualities desired. In general it has been found that the higher temperature ranges (150°C. and higher) and the more concentrated liquors (over 1.00 pound per gallon) produce the strongest pulps. Brightness is most likely to be impaired in pretreatments of this type but for applications where color is of minor importance, the greatest strength may be achieved. In cases where brightness and color are of major importance, it is necessary to adjust the temperature-time cycles in order to produce pulps which are readily bleached and yet have reasonably high physical strength characteristics. Low temperatures and low chemical concentrations produce the brightest, bulkiest pulps, having the lowest physical strength values.

Power and Pulpstone Requirements

The pretreatment of both aspen and the dense hardwoods so modifies the wood that power requirements on the grinder are greatly reduced over those

required for grinding spruce or untreated hardwoods. Spruce groundwood pulps require an average power input of about 70 horsepower days per ton while pretreated hardwoods require only about 35 horsepower days per ton for grinding. Production rates, expressed as tons per square foot of grinding area, have indicated that the pretreated woods can be ground into satisfactory pulp at from two to three times the rate for normal softwood mechanical pulp production. Stone wear is reduced to a minimum and the time between burring cycles is greatly extended. In respect to stone life, laboratory stones have been run for more than 400 grinding hours without reburring.

Chemigroundwood pulps may be successfully and economically bleached to medium or high white brightness with either sodium or hydrogen peroxides employing the same techniques and equipment currently used for groundwood bleaching. Recent work has shown that highly buffered calcium hypochlorite may also be used to great advantage in improving the color and brightness of these pulps.

Possible Applications

With this brief review of the chemigroundwood process and the indication of the range of pulps this process offers the paper-maker, the possible applications of these pulps may be pointed out. The concept of "quality" in pulp, as in any commodity, will vary considerably with the point of view of the consumer. For example, a manufacturer of absorbent tissue grades would consider a pulp of good brightness, bulk and softness as having qualities he desires. Bleached chemigroundwood pulps of the high bulk types can well fit these requirements. The producer of book or printing grades desires cushion, good formation and opacity in his product as well as physical strength sufficient to carry the paper through the presses. Bleached or semi-bleached chemigroundwood pulps of the medium strength categories possessing good bulking characteristics may well find wide application in this field. In the production of corrugating board, liner board or wrappings where color is of minor importance and physical strength constitutes the most important quality, high strength chemigroundwood pulps appear to have good potential applications. These are only a few of the possible uses of these exceptional groundwood pulps.

Economic Advantages

The high yields of pulp obtained from the more dense hardwoods, coupled with greatly reduced power requirements for grinding, high production rates, and the upgrading of pulp quality achieved by the chemigroundwood process make the process extremely attractive from the economic standpoint. By conservative estimate based on average cost figures for wood, labor, steam and chemicals, the cost per ton for producing chemigroundwood pulps of high quality is between two-thirds to three-fourths of the cost of producing normal spruce mechanical pulps. The fact that chemigroundwood pulps may be used to replace some of the more expensive chemical pulps in papermaking furnishes serves only to enhance the economic advantages inherent in this process. Plant investment required to install the chemigroundwood process in a groundwood mill is lower than that required for other processes utilizing hardwoods for pulp production.

Summation

In summation is may be said that the versatility of the chemigroundwood process and the wide range of pulp qualities obtainable through control of the treating conditions will permit those skilled in pulp making to utilize available hardwood species formerly considered unsuitable for mechanical pulp manufacture. The high yields of pulp obtained, the low power requirements and high production rates achieved in grinding, coupled with the desirable qualities of the pulps combine to present an economically attractive process for the pulpmaking industry. Commercial application of this process should go a long way in re-establishing a favorable economic base for mills in those areas in which softwoods are in short supply and permit, with good forestry practices, the establishment of a continuous supply of pulpwood essential to their continued operation.

Discussion

W. E. M. Logan (Forest Dept. Kenya, East Africa): Has the process been tried with any tropical or sub-tropical hardwoods?

Mr. Schaffrath: No experimental work has been carried out on these species.

Walter H. Koepp (Michigan College of Mining & Technology): How is the bark removed from the hardwood pulp sticks prior to treatment?

Mr. Schaffrath: Most of the wood is sap-peeled although some mechanically barked or rossed wood has been used experimentally.

Mr. Koepp: Will this process apply to all species?

Mr. Schaffrath: Northern hardwood species seem to respond most favorably to treatment by the chemigroundwood process. There is still not enough experimental evidence to warrant conclusions on other species.

John Hanson (Michigan Dept. of Conservation): Have pulp mills in this region found it necessary to offer any special inducement to encourage pulpwood cutters to produce hardwood pulp species?

Mr. Schaffrath: Mills have not yet gone into commercial production. Inducements required will de-

pend upon individual mill conditions and local wood markets.

Mr. X: What possible effects would the industrial application of the chemigroundwood process have on forest management practices in the Northeast?

Mr. Schaffrath: The development of this process which permits the economic utilization of hardwood species, would possibly stimulate the acceptance of more scientific management of hardwood stands and lead to a sustained yield forest program. The suitability of fast-growing hybrid poplars in this process may also stimulate more intensive tree farming in these areas.

Mr. X: Does the physical condition of the wood influence the choice of treating conditions?

Mr. Schaffrath: Yes. In the case of freshly-cut wood with high moisture content, higher chemical concentrations in the treating liquors are required. Generally moisture contents above fiber saturation are undesirable because free water reduces the rate of penetration of the treating liquors. In cases where considerable "wet wood" or impenetrable heartwood portions are present in the wood, temperature schedules may have to be adjusted to prevent excessive heat discoloration of these portions in the treating operation.

Mr. X: Do southern hardwoods respond in the same way as northern hardwoods to the chemigroundwood process?

Mr. Schaffrath: While experience with these woods is limited, it appears that woods such as gum and oak do respond to pretreatment but require slightly different techniques than those employed for northern hardwoods.

Mr. X: It is possible to produce pulps similar to semi-chemical pulps by the chemigroundwood process?

Mr. Schaffrath: Yes. Pulps with physical strength characteristics very similar to semi-chemical pulps have been produced in high yields with this process.

Mr. X: Is this process covered by patent protection?

Mr. Schaffrath: The chemigroundwood process has been covered by patent claims designed to protect the interests of the sponsors of the research program. If patents are granted, it is the intention of the sponsors to make them available to the industry at nominal fees.

First Chemical Pulp Utilization in the State of California

C. L. MOREY, *Manager Timber Division, Fibreboard Products Inc., East Antioch, California*

The overall state of the supplies of wood for the forest industries is surveyed as well as the results of scientific and empirical research looking to the reduction of wood residues and the profitable growing of timber.

New Plant at East Antioch

AS THE attention of the forest products industries of the United States turns more and more to the complete use of all the materials taken from the forest, the eyes of the industry are focusing on East Antioch, California, for here, at the new San Joaquin Division of Fibreboard Products Inc. is one of the most complete wood utilization programs in the nation.

It was during the war that executives of Fibreboard Products, Inc., envisioned a great pulp and board mill on the banks of the San Joaquin River just four miles east of their long-established plant in Antioch. The new plant is part of a 10-year expansion and plant betterment program started in 1946, involving capital expenditures upwards of $50,000,000. The San Joaquin Division, together with the timberlands, private railroad, private logging roads, and receiving yards located at various points in the state represents a total outlay of many millions.

Fibreboard began acquiring forest lands in 1947, purchasing in excess of 75,000 acres in eastern California and western Nevada. Majority of the acreage lies in Placer, Nevada, and Sierra counties adjacent to Truckee, California. Hobart Mills, a former sawmill town, seven miles north of Truckee, was purchased as a headquarters for logging activities.

The U. S. Forest Service and private owners also control a large acreage of timberland tributary to Hobart Mills and Truckee. Fibreboard hopes to develop a cooperative cutting program with the government and other owners, whereby orderly cutting will maintain a growing, producing forest for all time. Forest lands near Truckee are primarily a reservoir of supply for the San Joaquin Division mill at East Antioch.

Here are principal facts about the new San Joaquin Division of Fibreboard Products, Inc:

It is the only wood pulp and board mill in California, or anywhere west of Texas, and Minnesota, outside of Washington and Oregon. It is the first kraft mill in California and the first chemical process mill of importance since a sporadic venture into sulfite in the last century in this same region.

Wood Supply: Timber supply will come from cull logs in virgin timber (mostly red and white fir) from 75,000 acres owned by Fibreboard, Douglas fir pulp-grade logs from the coastal region of California, waste from sawmills where Fibreboard has installed chippers, and waste from planing and plywood mills and box factories.

"Tuf-Fir" Mill: The new "Tuf-Fir" Mill makes new .009 kraft corrugating material, said to be the first ever made 100 percent of coniferous wood by the Chemipulper-Defibrator system, trade marked "Tuf-Fir", daily capacity 140 tons. The mill will use wood waste 3,000,000 board feet per month, equivalent to 6,000 cords. Incoming chips are stored in two new-type outdoor 75- by 1,600-foot storage troughs. From there they are conveyed to blending tanks and screens, following that in order to 3 American (Asplund) defibrators with B–K Reaction chambers, 2-stage IMPCO washing system, Sutherland refiners, Jordans, a Pusey and Jones 156-inch Fourdrinier seven-action machine with GE sectionalized amplidyne drive and Ross air system. Spent liquor from defibrators is recovered in the kraft mill.

Kraft Pulp and Board Mill: The kraft pulp and board mill is making cartonboard for food containers, from bleached pulp, daily capacity 125 tons of board and 25 additional tons of unbleached pulp for other Fibreboard boxboard plants. (Uses pulp grade logs at a rate of about 4,000,000 board feet per month, the equivalent of 8,000 cords.) Briefly, the process is as follows:

Logs are hydraulically barked by a Bellingham-type barker; 20-foot logs up to 42-inch diameter go through a 175-inch chipper; smaller wood to an 84-inch chipper. Large chipper is believed first in entire industry to be driven directly by a steam turbine, through a gear unit. There are three 3,800-cubic-foot stainless-steel lined digesters equipped with indirect cooking, believed to have the largest blow lines in kraft industry. This is followed by Impco washing, screening and decking, Impco four stage bleach process, Sutherland refiners, Jordans, 136-inch Black–Clawson 10-section machine with multiple generator drive, and a Langston winder.

Water use from the San Joaquin River totals 14 million gallons daily. A Dorr clarifying system is used. Principal chemical units are Goslin–Birmingham sextuple effect evaporators, Babcock and Wilcox 100,000-pound-per-hour, 600-pound-pressure-recovery boiler; Research Corporation, precipitator; Dorr causticizing, Swenson sludge filter, Allis–Chalmers lime kiln. Two B & W boilers of 160,000 lbs. per hour capacity at 600 lbs. pressure each, and GE 5000 KVA turbine generators and Westinghouse switchgear feature power plant.

Aside from the physical operation of the San Joaquin Division, Fibreboard and the entire industry are chiefly concerned with the base resource—wood. The forests are not so meager as to cause public alarm, nor are they so abundant to justify complacency. The nations wood supply is not being depleted, nor is it mounting into a surplus.

Evaluating the Forest Resource

Today the forests of the United States are estimated by the U. S. Forest Service to contain 1,601 billion board feet of timber or in other words there is enough sawtimber standing in the nation's forests today to build a six-room house for every man, woman and child in the United States, with lumber left over. Each year, new growth adds 35-billion board feet.

During the past 350 years twice as much wood has been removed from America's forests as was growing here when the first English settlers arrived. A little over one-third of it was used for man's needs and comforts. The remainder was destroyed by fire, insects and disease.

United States Forest Service Statistics show that:

(1) In war and in peace this nation's forests have met and are meeting the demands made upon them.

(2) Each year new wood growth of all sizes equals 98 percent of the amount removed and destroyed. Only 25 years ago, 4½ times as much wood was removed as was grown.

(3) For 30 years there has been a definite upward trend in annual growth. The timber crop is approaching a balance with wood consumption.

Maintenance of this trend depends on the attitudes and actions of timberland owners, forest products industries, government agencies and the public generally. Each has a definite and important stake in the forest resources. Each has a specific and vital job to do if full and continued use of the country's forests is to be achieved.

Over 300 years ago, the American was concerned about his supply of wood. He had too many trees, a timber supply far in excess of his needs. He had to have cleared fields for his crops; the forests stood in his way. Today, three centuries later—with his nation built, the American citizen still is concerned about his wood supply. World War II's channeling of forest products away from their traditional uses increased public concern. Many people gained an impression that the nation is running out of wood. This time, it isn't a matter of too many trees. The question is how much lumber, pulpwood and other usable products are now in the forests? Is there enough now, and is enough growing for the future? Not in three centuries has there been so much public interest in the wood supply as there is today. More people are having more to say about forest resources than ever before.

Of course trees are being cut. They are harvested as cotton and corn are harvested and for the same reason—to supply man's needs. To read statistics on volume of wood being removed from forests, without considering new growth, and from this conclude the wood supply is reaching an end, is unrealistic. It is just as illogical to read the obituary column in a newspaper while ignoring the birth column, and thereby conclude man is becoming extinct. In 1944, timber consumption plus estimated losses from fire, insects, and disease, amounted to 54-billion board feet. Even if all growth had stopped then, and consumption and losses continued at that war-year rate, the existing timber supply would last for decades. Of course, forest growth never stops. It has been increasing steadily since the first detailed estimate was made 30 years ago. In fact annual timber growth now is nearly four times greater than in 1918.

Measures to Reduce Waste

Until recent years, if more than 37 percent of a tree trunk reached its ultimate use, it was a real achievement. Today, in some of the larger forest industry plants, 70 percent of the entire tree-trunk, branches, tops and bark goes into commercially useful products. Such ultra-utilization is not widespread, but the trend has started and is moving rapidly. When all of the larger operations reach this goal, their wood savings alone will add greatly to the volume of usable timber products.

Industry's ideal method of attaining maximum use of the individual tree is the integration of several manufacturing operations at one site. Although small firms are not set up to utilize wood so closely at individual plants, a trend has started among them to add additional units whereby many leftovers once wasted can be turned into profits. Some have included flooring plants, others have installed chipping plants for pulpwood, and lately small dimension manufacturing units have been added.

Equally indicative of the trend is the increasing integration of several *industries* in one area. One industry's waste has become another's basic raw material. Sawmill operators provide neighboring pulp mills with pulpwood, and pulp mills in turn may sell sawlogs to sawmills.

Progress in utilizing more of each tree has been augmented by improvements in mechanical equipment. Power saws encourage cutting trees nearer

the ground, leaving less wood in stumps. Modern logging equipment minimizes damage to logs and nearby young growth. Hydraulic methods of removing bark and the use of whole log chippers reduce wood waste by as much as 10 to 15 percent.

Achievements of Research

Industry's progress in forest conservation and wood utilization may be attributed largely to research. In hundreds of forest research projects, scientists are seeking new uses for wood. Reproductive and growth habits of each commercial species have been studied in widely separated timber tracts. More basic knowledge of all trees, particularly so-called "inferior" or "weed" species, has been developed. Research technicians in government, college and university and industry laboratories have put innumerable wood specimens through chemical and mechanical tests to develop new uses and products. They have converted wood waste into raw materials having no appearance of natural wood, but with broad use in new products. For instance, wood ground into flour makes a binder for plastics, wood cellulose transformed into fine thread makes rayon, wood, through chemical reactions, produces molasses for stock feed, and alcohol for industry. Thin wood sheets, soaked in resin and placed in layers under heat and pressure, emerge as a much harder material that retains wood's appearance. Chips, shavings and sawdust, mixed with resins into a batter and pressed under heat, become building boards.

Progress in wood conversion techniques is making an important contribution to the nation's wood supply through use of trees formerly considered unsuitable for cutting, and of tree wastes heretofore of no value except as fuel. Improvements in equipment and methods used in logging operations, sawmills and manufacturing plants are reducing wood losses and producing better, more economical wood products. Every saving in wood use reduces waste, thereby increasing the volume of products from each tree.

Nearly $17,000,000 was spent in 1949 on forest research in the United States, of which $11,907,472, or 71 percent, came from industry, state agencies, private institutions and colleges. This was 230 percent more than was spent in 1940 by these nonfederal agencies. Industry provided $5,395,210, or 32 percent of the 1949 total. In addition to spending $12,000,000 annually for research, state and private agencies provided $3,500,000 worth of land and equipment to the U. S. Forest Service for experimental purposes in 1949. This is a 600 percent increase over 1940.

There are no satisfactory figures on waste of forest products destroyed or not used which are economically and technically usable. The Forest Service estimates, based on its definition of waste as any wood product not used regardless of its economic value, that 35 percent of the timber cut or damaged in cutting is not used at all and 22 percent is used for fuel (other than cord wood cut for fuel) in a relatively uneconomical manner. Much of this waste may not prove to be usable at any time in the near future. It appears likely, however, that substantial quantities could be used for pulp or other fibre products. In fact, some of the larger operators have invested considerable sums in equipment to produce by-products and obtain as near complete utilization of forest products as present day techniques will permit.

More work remains to be done. The Forest Products Laboratory of the United States Forest Service, the laboratories or forestry schools at the state universities in California, Oregon, and Washington, and private industry may be able to make even greater progress than heretofore.

Competition for Stumpage

One of the major problems confronting the wood using industries is the competition for stumpage. Even though figures show a large stand in the Pacific Coast area, the most accessible timber has been drawn on heavily. At the same time, the plywood and pulp industries have increased their use of timber supplies. Plywood production requires large high-grade logs, though the pulp industry can use smaller, lower-grade logs, and salvage material from sawmills. Nevertheless the several demands for logs create a situation in which logs will tend toward the use bringing the highest return. Since wood consuming plants such as plywood, pulp and sawmills represent a great variability with respect to installed cost, it is logical that those operations with the highest investments will be the most active in seeking long-range timber supplies.

Harvesting Practices

Integration in the State of California, must follow a somewhat different course than other regions since the timbered areas of the state are in two widely separated areas, the Coast and the Sierra, with divergent practices and problems. For example, in the Sierras partial or selective cutting has been a common practice in most areas of the ponderosa pine region for a considerable time. The employment of partial cutting does not always assure that the best cutting practices are being observed. For example, if all trees of positive value are removed, some trees may be taken which would have a considerable growth if permitted to stand for a longer period.

Since the ponderosa pine forests are largely mixed age stands, selective cutting is favored by the circumstances. The goal should be to remove all mature trees (not only for their timber value, but also to reduce possible insect loss), stimulate growth of thrifty trees, and hasten reproduction. Trees having a potential high-value growth increment should be permitted to stand for cutting in the future. It appears that these aims might make for a lighter cut than has heretofore been the practice on a substantial portion of the operating lands. On a number of

operations light cutting is already the practice. Policies in exchanging Federal stumpage for private lands may make the extension of the practice more feasible.

However, on the Coast there are mixed stands of Douglas fir and other species, many Douglas fir forests tending to be homogeneous. Selective cutting—removal of mature trees or high quality trees only—is not the desirable practice in such stands. Douglas fir tends to grow in uniform age stands and requires a considerable amount of sunlight. Regeneration requires clear-cutting the land in such a manner as to permit adequate reseeding and adequate sunlight for the young stand. This practice is now followed on most well-managed operations by clear-cutting in blocks of from 40 to 100 acres and leaving seed trees in fairly substantial blocks about the cutover area. Some controversy exists as to the size of the area that should be cut over, but in general the principle of clear-cutting is accepted. Leaving seed trees dispersed over the area, which might suffice in other stands, will not do for Douglas fir. Trees not protected from the wind tend to blow over, except on gravelly soils, because of the root structure. The practice of leaving the seed trees adjacent to the area has proved to be the most satisfactory method. The difference in cutting practice is reflected in the waste factor from logging and sawmill operations and has a direct bearing on pulp wood procurement.

It Pays to Grow Trees

Today, more than ever before, it pays to grow trees! The profit motive now gives greater incentive to owners of timber tracts and woodlots to grow, protect and harvest trees as a crop. Within the past decade, American forestry has been undergoing a transition from the old economy into a new, more stable one. The old economy was one of forest liquidation. As population increased, the necessity for cleared land grew. The abundance of trees made wood excessively cheap and encouraged extravagance. Throughout most of the nation's history, wood-dependent industries have drawn on virgin forests, a stockpile of raw material prepared and waiting for them. That economy now is coming to a close. Timberland ownership is passing into a new phase—the economy of tree growing—tree farming. Virgin forests have been removed from more than 90 percent of the commercial forest area. The bulk of future timber production must come from new forests. The nation's timber growth has climber steadily since 1900 as static old-growth forests were removed and management of second-growth forests improved. As long as standing timber was available at 50¢ to $1.00 per thousand board feet, it was more economical for a sawmill to pack up and move than to grow its timber. But today, the value of timber in the United States has risen to the point where it now pays, in most areas, to grow trees as a crop.

Emergence into the new forest economy by private industry has brought unprecedented progress in protection and overall management of timberlands, in utilization of forests and forest products and in the technique and equipment used in harvesting and processing. It has done much toward solving forest reproduction, reseeding and planting problems.

Discussion

E. G. Locke (Forest Products Laboratory): Utilization of sawmill and veneer plant left-overs at this mill has done much to teach the mill operators the value of working together and with other groups. I understand that the timberland purchased will be used as a stand-by and that the main supply of raw material comes from other primary plants. Stream pollution has been solved by putting the waste liquors of the semi-chemical mill through the kraft recovery plant.

C. R. Silversides (Albitibi Power & Paper Company): Please give some details of your method of outdoor storing of chips—is there any apparent heating or deterioration of chips—what type of waste is used?

Mr. Morey: The chips are piled to a height of approximately 50 feet from the bottom of the trough, which is 20 feet deep. The trough was bulldozed out of the earth. Our mill is situated on a river bank and the soil is 100 percent sand. This made it necessary to oil the sand in the troughs to hold it in place. However, with a more stable type of soil, we question that this would be necessary. We leave from 12 inches to 18 inches of chips in the pits at all times, and in that way we do not pick up any sand or dirt when the chips are reclaimed from the pits.

As a general practice the chips are left in the piles from eight to ten months, but at one time they were left there for about twenty-four months without serious deterioration. The highest temperature recorded in the piles to date is 107° Fahrenheit. In regard to mill waste we are using sawmill slabwood waste, box factory and planing mill trims and ends, waste from plywood mills in the form of cores, reject peeler blocks, and reject veneer sheets. An article in the June, 1950, issue of "Pulp and Paper" enlarges on the information presented in my paper and includes photographs which you may find of interest.

The Utilization of Wood Waste in the Manufacturing of Chemical Pulps in the Pacific Northwest

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The development of heavy modern chipping and barking equipment has greatly increased the tonnages of goods and sawmill wastes available as operating supplies for chemical-pulp conversion in the Pacific Northwest. The use of new equipment and methods is especially significant in the case of the tree-farm integrated-plants combination. The development of and general use of universally-reliable measurement methods for the waste materials would be desirable.

Introduction

THE use of wood waste in the production of sulfite and sulfate chemical pulps is closely related to a number of economic factors which must be considered parallel with technical developments also affecting wood waste utilization. This discussion is intended to highlight-wood use changes and the basic causes of such changes in the production of chemical pulps from coniferous species, particularly in the Pacific states and British Columbia, as this area has been a primary producer of so-called "wood waste" since the advent of the earliest settlers.

Early Raw-material Economics

In the early days the heavy equipment needed for logging large timber, rough terrain, and similar well-known difficulties encountered in bringing select Douglas fir logs to the sawmills, made a type of "high grading" the only economically practical method of obtaining any return from the overripe forests of the area. Douglas fir had the desirable high strength properties and good durability for construction and finish lumber and along with western red cedar for shingles could sustain a permanent place in the local and national markets. Transportation costs plus the availability of, and primary demand for clear Douglas fir lumber stock made it economically impossible to use the lower grade material and secondary western hemlock and true fir species in proportion to their availability. Thus, to the extent this wood could not be used, it was left in the woods.

The era previous to 1920 saw the beginnings of the chemical pulp industry in the area and the ready availability of low-cost hemlock made it the principal species used, although the earlier mills, with production consisting largely of newsprint, depended chiefly on cottonwood, and sitka spruce. During this era the true firs and Douglas fir were used to only a slight extent in pulping. In 1921 the total Pacific states production of all types of wood pulp was approximately 220 thousand tons and by 1949 this production had increased approximately 10 times to over 2 million tons. During this period two general developments in increased chemical pulp production took place.

First, because of the ready availability and low cost of the sulfite species of western hemlock and the associated true firs plus pulping and paper making technical developments, a great expansion in the production of many types of sulfite pulps took place. The waste aspects of the use of hemlock were secondary during this period except to the extent that subsidiary species having a lower market value found a steady dependable market. In many instances this also was the beginning of an integrated forest products industry, since in several mills desirable lumber or box material was removed from the logs previous to chipping and pulping. This development was also important in the gradual evolution of forest management plans for Pacific coast forests in that the large investments inherent in chemical pulping operations necessarily implied a steady market for wood supplies.

Important factors in this sulfite pulp expansion were the technological advances in bleaching equipment and knowledge, the wider use of strong acid systems, and the realization by eastern paper makers and the cellulose chemical industry that western hemlock could be processed to produce several types of high-grade desirable wood pulp. Between 1920 and 1930 pulp production had doubled in Oregon and British Columbia while Washington showed an increase from 95,000 tons per year to 566,000 tons. Kraft mills were also established to a lesser extent in this decade and a number of the new mills were set up to operate largely on hemlock, spruce and Douglas fir mill waste. An outstanding example of one type of cooperative operation was the Longview Fibre Company kraft mill designed to operate on the Douglas fir mill waste of the large adjoining sawmills of the Long–Bell Lumber Company. The Longview Fibre mill began operations in 1927 and has continued operations to the present time on an

ever expanding scale in which sawmill waste has been a major source of raw material.

By 1929 the pulp and paper industry had also become a primary customer for hog fuel wood manufactured to supply the mill power requirements. Approximately 25 percent of the hog-fuel production in the Pacific Northwest was used in the pulp and paper mills.

Between 1931 and 1940 the installed daily 24-hour capacity for chemical pulp production increased in Washington from approximately 2,300 tons to 4,100 tons while moderate increases in mill capacities took place in Oregon and British Columbia to give a general increase for the period of from 3,475 tons to 5,700 tons. The increase was largely in sulfite production, 2,000 tons per day of increased capacity being built during this period.

Influence of Modern Barkers and Chippers

In 1942 the first commercial hydraulic barker and whole-log chipper were placed in operation at the Everett Sulfite Mill of the Weyerhaeuser Timber Company. As you undoubtedly know, several types of hydraulic barkers have been designed and the several types have been installed at many of the mills since that time. This development has had a far-reaching effect on the utilization of waste in both sulfite and sulfate pulping in recent years. The immediate effect of whole-log barking and chipping was the virtual elimination of sawmill breakdown equipment and power barkers for cants and slabs. This resulted in approximately 20 percent more wood in the form of usable pulp wood chips which had formerly been reduced to sawdust and hog fuel by the saws and power barkers. The only loss that might be called wood waste ahead of the chipper was the loose slivers on the logs and a minimum of saw kerf loss for the small percentage of logs too large or irregular in shape for chipping. These large logs, sectioned on a simple band mill subsequent to hydraulic barking, were readily chipped in the form of quarter or half logs.

Two further developments in hydraulic bark removal have occurred in the building of slab and small-log barkers. Both types of equipment in various designs are now found in general use in many mills. The slab barkers have made practical the wider use of sawmill waste where primary hydraulic barking is not done by making barking less hazardous, and saving a much higher percentage of usable wood for chips than was possible with power cutter-knife equipment. It is difficult to separate from general sawmill waste use, the added pulp wood production due to hydraulic barking of slabs. However, a general indication of the increased wood for chipping made available by the removal of bark from slab wood is found in an estimate of the difference in the amount of bark-free wood available for pulp chips from two Douglas fir sawmill operations. In one of the mills the logs were barked previous to sawing. This resulted in 73 percent more usable, bark-free wood in the form of chips, from sawing the logs which had been previously barked. Stated another way, if it is assumed that 2,300 board feet log scale are required to produce a ton of dry, bark-free wood in the form of chips in a conventional sawmill without a hydraulic barker ahead of the mill, the addition of a barker would make it possible to produce a ton of dry chips for each 1,320 board feet log scale cut. This would indicate that a ton of dry wood in the form of slabs containing bark is recovered for approximately each 1,000 board feet log scale. These log-scale-per-ton-of-chips values of course must be considered only in the nature of an illustration as they will change with each type of lumber cut, with variations in mill equipment, size of logs and species cut.

Amounts of Waste Used

A general survey of the amount of sawmill waste utilization by sulfite mills at the present time results in an estimate of 5 percent of the total wood supply, with various mills using from zero to over 15 percent hemlock and other suitable sulfite sawmill wastes. With approximately 1¼ million air-dry tons of sulfite production expected in the Pacific Northwest for 1951 the amount of pulp derived from sawmill waste can be estimated at 60 thousand AD tons. The use of sawmill waste for kraft pulp production, consisting primarily of Douglas fir mill waste, presents a very different picture than that of sulfite. Kraft pulp mills use from 30 percent to over 80 percent of this type of wood with an estimated overall percentage of 50 percent. There are 7 kraft mills in the Pacific Northwest; all with the possible exception of one use sawmill waste as a sizeable part of their wood supply. With approximately 700 thousand AD tons of sulfate pulp production for 1951, the amount of pulp derived directly from mill waste can be estimated at 350 thousand AD tons. The total chemical pulp production directly derived from sawmill waste wood is thus estimated to be over 4 hundred thousand AD tons, for the Pacific Northwest in 1951.

Another type of wood waste of a similar nature which has come into general use for chemical pulp production is the residue from plywood plants. This waste is in two forms—chipped veneer waste produced with veneer chippers, usually at the plywood plant, and to a smaller extent peeler cores which are competitively used for fuel and as small saw logs. This material is used largely for sulfate pulping as the plywood industry in the Pacific Northwest uses, predominantly, Douglas fir peeler logs. The percentage of sulfate wood supply derived from plywood plants is estimated at 12 percent of the total. This 1951 production is expected to be equivalent to approximately 85 thousand AD tons of sulfate pulp.

New Methods and Equipment Aid Bleached Kraft Supply

Just as the development of better bleaching techniques contributed to the growth of the western hemlock sulfite pulp mill expansion by supplying high-grade pulps for eastern markets, the formulation of successful commercial methods for the bleaching of top grade kraft paper pulps, particularly Douglas fir, has and is contributing to the building of a bleached kraft industry. This development was necessary to obtain full use of the potential wood supply and sufficiently widen the markets for sulfate pulp beyond the board and unbleached kraft paper field thus forming a balanced sulfate pulp industry.

The whole-log hydraulic barking machines are making a joint technical contribution with bleaching methods to this pulp expansion by providing much larger quantities of sawmill waste and contributing to the practical utilization of both small and large marginal-value logs from woods operations. The barking of sawmill logs before reaching the head rig, as previously stated, increases by approximately 73 percent the clean bark-free usable wood available for chips. This has been particularly important on the mill waste utilization scene as the large quantities of clean wood produced have given added impetus to the development of bleached kraft pulp production of high-grade paper pulps for eastern markets. The relatively complete elimination of bark from the chips is of much greater importance for this type of pulp.

Small-log Use

The hydraulic barkers have also contributed greatly to the increased use of small logs and marginal value cull and "wood" logs. The wood-log grade is a designation for a log which is below No. 3 grade and above the cull. They are usually the major product of logging salvage operations. The cull or wood logs would normally be left in the woods if logging operations were carried out only for sawmill operations. However, they contain large portions of usable fiber for pulping. The good sound fiber in these logs often tends to lie near the bark so that much of this good wood fiber would be lost except for hydraulic bark removal. The same advantage applies to the prelogging or relogging of small logs from small trees associated with stands of large timber. Mechanical barking of this material causes large percentage losses of good wood and drum barking increases the dirt problem in connection with the bleached pulps. Hydraulic barking has thus widened the use of both small sound logs and large marginal value logs.

The combined use of cull and wood logs together with small prelogged and similar wood waste including salvaged material is relatively a small percentage of the wood supply for sulfite operations, approximately 4.5 percent of the total wood use. This includes about 65 percent western hemlock, the remainder being true fir with a small percentage of spruce. This represents roughly 55 thousand tons of AD sulfite pulp production from types of wood which were largely logging waste in the 1930's.

The use of this salvage and lower-than-lumber-grade type of material in the form of Douglas fir for sulfate pulp constitutes a major portion of the wood supply. It is estimated that about 25 percent of the wood used in producing sulfate pulp in the Pacific Northwest is directly derived from this grade of wood. This will account for approximately 175 thousand AD tons of pulp in 1951, giving a total of 230 thousand AD tons of chemical pulp production from salvage logging of material formerly considered waste. No attempt has been made in this paper to discuss the many experiments and variations in method of bundling or bringing logging waste to the mills. Many salvage methods and experiments have been adequately discussed in current literature and are now evolving into commercial usefulness.

Material Must Be Competitive

However, one principle must always be remembered in relation to the successful use of any forest product, whether it be sawlogs or the types of waste under discussion here. The cost of removal, handling and processing to the final usable form, chips in the case of chemical pulps, must (1) be competitive or cheaper than material produced from logs by conventional methods, and (2) be obtainable in reasonably sustained and sufficient quantities to justify the capital investment in handling, barking or other necessary equipment for final conversion. Large quantities of existing waste material are at locations which cannot be profitably recovered. Of course, under any type of allocation or artificial conditions such as may develop in times of war or national emergencies, the economic laws of supply and demand are restrained as we all well know. The shortages in pulp wood which developed during the 1940's were in many cases primarily due to shortages of equipment or manpower or both, but the emergency salvage methods developed during that period have in many instances proven to have a permanent place in the industry.

Tree-farm Integrated-plants Operations

The development of tree farms and permanent forest management plans for forest land areas are becoming a part of the operation of most large-scale pulp producers in the Pacific Northwest. The plants suitable for integrated utilization of the variable types and species of wood found in our forests and the developed wastes from these plants must be efficiently used for sustained yield operation of the forests. This condition is usually most efficiently realized under conditions of large forest-land ownership or management serving large manufacturing

plants and balanced with the production capacity of the forest, in both type and quantity of wood.

The Longview operation of the Weyerhaeuser Timber Company is an outstanding example. Logs suitable for the production of lumber, plywood and sulfite pulp are concentrated at the plant site from logging operations, principally on the nearby St. Helens Tree Farm. All of the types of sawmill waste previously discussed are converted into chips at convenient sites and conveyed to the sulfate pulp mill bins. Prelogged small-diameter logs in bundles from the woods operations are also a contribution to sulfate pulp production after passing through a small-log barker. Cull and wood logs are removed in the primary logging, hydraulically barked, and chipped in a whole-log chipper. These chips added to chips from other waste makes up practically all of the required wood for the 200-ton bleached sulfate mill. In such an integrated manufacturing-and-tree-farm operation additional by-product developments include the production of pres-to-logs for domestic fuel from low-moisture-content finely divided planer mill waste, and the manufacture of several useful products from the bark separated from the peeler logs in the veneer plant.

The large investments involved in hydraulic barkers, to say nothing of pulp mills, makes complete wood utilization difficult for the small sawmill or wood manufacturing plant. However, a trend towards more complete utilization of wood wastes at a profit in these mills is indicated by the fact that over 60 chippers have been installed or are about to be installed in connection with sawmill and plywood plants in Washington, Oregon, and California. Chips from these will add to the supply for existing kraft pulp mills.

The Problem of Wood Measurement

With the utilization of so many types of wood waste in the production of chemical pulp, wood measurement methods have become a major problem. Measurements in cords, log scales, chip and waste units, and by weight result in a very complicated picture in which many conversion factors, subject to wide errors, are involved. An analysis of the basic variables inherent in such measurements appears to be in order. Pulp production is universally measured by weight in air-dry tons. The important measurements to the pulp producer are weight yield in percentage and weight yield per unit volume of digester space. Weight yield per unit volume of digester space is a direct function of weight of chips per unit of volume and thus of weight per unit volume of solid wood as received. The logical method of measurement of wood as a pulp raw material is either by AD weight or by actual volume of solid wood. The more common methods of wood measurement are based upon a log scale or cord measurement. Both of these present difficulties in calculating exact amounts of wood available for pulping.

The commercial log scale measurements are designed to measure the board feet of lumber that may be cut from a log and not necessarily its total wood volum. The relation between log scale and wood volume varies with the size of the log. For example, using an average specific gravity of 0.45 and the log scale rule for 32-foot Douglas fir logs, a 50-inch-diameter log gives 515 bd. ft. for each ton of wood; a 10-inch log gives 274 bd. ft. per each ton of wood. Thus, log scale is not directly related to the weight of wood or the weight of pulp that can be produced from a given log. Variations in trim and defect subtractions normally applied in log scaling also have a marked effect on the weight per unit of log scale.

Cord measurements are inaccurate in small-log wood because of variations in voids. This difficulty becomes particularly great in prelogged wood because of the common practice of bundling logs of long length together with straps and handling the unit bundle. Volume measurements of mill waste are also subject to great variations as regards voids and if the wood is closely piled often cause an increase in cost due to the labor involved in stacking. An average cord is often estimated to contain 90 cubic feet of solid wood and variations will often be as great as 10 cubic feet per cord. At 90 cubic feet per cord Douglas fir of normal density will yield an AD ton of wood for each 0.71 cord. At a wood volume of 80 cubic feet per cord the yield will be an AD ton for each 0.80 cord. Variations in bark thickness and the trim length of limbs as well as other individual wood shape variations all lead to inaccuracies in cord measurements. The labor involved in measuring cord wood must also be considered in any evaluation of pulp wood measurement methods.

Weight measurements also include large inherent errors but they are usually subject to close control and check procedures. All wood weights are subject to moisture variations in evaluating the amount of dry wood available. These variations may take the form of sapwood and heartwood differences; in Douglas fir the moisture content of heartwood is in the range of 27 percent while the sapwood contains about 60 percent moisture. The moisture differences also extend from one species to another and slight moisture variations may be caused by storage of small sawn wood waste. These moisture variations are subject to easy measurement in the pulp mill on the chips produced and the moisture content will normally be in quite close agreement for chips from similar wood sources. Weighing methods for waste material containing bark is subject to the same criticism as the volume measurement but variations in void volumes are eliminated and chip weightometer values may give accurate evaluations of the bark waste involved.

The weighing of logs water floated to the pulp mill cannot be readily accomplished but the board foot log scale in present use is obviously not suited

to the accurate measurement of wood for chemical pulping. A standard cubic foot scale with the defects subtracted according to their effect on pulping operations would be a constructive step in the use of low-grade marginal logs and salvage material for chemical pulps. For other types of wood waste a universal adoption of weighing methods would give the pulp mill a sound basis for price evaluation and any intermediate transportation system a positive weight basis for evaluating transport costs.

It is believed that careful consideration of measuring and weighing methods and location of weighing equipment by the pulp mills or those operations producing wood waste will pay dividends. In remodeling wood handling equipment or designing new mills, careful location of weighing devices for trucks, cars, and chips will save labor and stimulate closer and greater utilization of wood waste because accurate cost studies on salvage operations can be closely correlated with pulp mill yields of both chips and pulp.

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Discussion

C. R. Silversides (Albitibi Power and Paper Company): To your knowledge, has any work been done on the separation of bark from wood in chip form on the West Coast?

Mr. Hammond: Not as far as I know. Sapwood and bark are not separable because of similar density.

Mr. Silversides: Do you store chips outside or in bins only? Any particular reason?

Mr. Hammond: In chip silos. Reasonably uniform moisture content is maintained by inside storage, thereby maintaining more uniform cooking conditions.

Mr. X: Do chips from sawmills cost as much as mill waste chips?

Mr. Hammond: This would depend entirely on local market conditions.

Mr. X: Which species of western coniferous wood are suitable for sulfite and which are more suited to kraft pulp production?

Mr. Hammond: The spruces, hemlocks and white, or true, fir species are the only ones generally suitable for sulfite pulping. Virtually all wood species may be pulped by the kraft process.

Mr. X: What different types of whole log hydraulic barkers are in use in the Pacific Northwest?

Mr. Hammond: Barkers using high pressure water include three general types suitable for large commercial logs. As classified by the method of applying the stream of water these would be: (a) Ring barker, the log passing without turning on its axis thru a series of moving nozzles surrounding the log; (b) Longitudinal barker, the log rotating slowly under or over water nozzles moving rapidly along the log from end to end; (c) Lathe barker, the log rotating rapidly under or over relatively fixed nozzles with either the log or nozzles moving slowly in a longitudinal direction.

Mr. X: What is the yield of pulp from Douglas fir?

Mr. Hammond: Considering only grades of pulp going into the production of bleached paper pulp, the yield of pulp from wood on an oven-dry weight basis will vary between 38 and 44 percent depending on the type of wood used as regards percent sapwood, tree age, and degree of decay present.

Mr. X: What is the method of handling bundled prelogged material at the Longview operation?

Mr. Hammond: Trees to 16 inch maximum diameter of all species are prelogged ahead of the regular logging, using light equipment. With a minimum of bucking, the logs are loaded on logging railroad cars in bundles held with steel straps. On arriving at the mill they are unloaded from the cars in bundle form and placed on a deck of controllable chains moving at right angles to the length of the bundle. The straps on the bundles are cut and the individual logs are spread out on the deck by the action of the conveyor chains, each log dropping into a trough at the end of the deck containing a conveyor chain moving at right angles to the deck. The logs individually pass a swing circular cut-off saw where they are cut in 8-foot lengths. Then then pass through an Allis–Chalmers stream barker and the barked logs are chipped in a Carthige multi-knife chipper. The chips are utilized in the production of bleached kraft pulp.

Mr. X: Does the amount of bark on Douglas fir logs vary greatly with the size of the logs?

Mr. Hammond: The bark increases in thickness with increasing tree age but the weight of green bark expressed as a percentage of the weight of bark and wood in a log cross section remains about the same, approximately 15 percent, regardless of the tree age.

New Fiber Boards Made With Non-Critical Binders

ARMIN ELMENDORF, *President, Elmendorf Research, Inc., Chicago, Illinois*

In view of the possibility of an emergency shortage of synthetic resin for the manufacture of wood-particle boards, a survey of native and foreign boards made with non-critical binders is undertaken. Of the group including sawdust-concrete, cement-bonded shavings, and similar products improved excelsior fiber boards bonded with inorganic materials exhibit properties that merit serious consideration and further development.

Introduction

IN VIEW of the imminent possibility that all synthetic resins used for board manufacture may be placed on the list of critical materials essential to the war effort, it is pertinent at this time to make a survey of what has been done commercially in this country and abroad in the manufacture of wood fiber or particle boards involving the use only of binders that will probably continue to be available for civilian production. In such an analysis it is desirable to consider the peacetime market potentialities of the various boards made with non-critical binders, as well as their war time uses. It is often easy to sell products in war time that cannot compete successfully in the free-for-all competition of normal times. The boards must have properties that are unique or that added together outbalance those of competitive products of the building industry.

There are at least three types of inorganic binders useful for board manufacture which are all available in such large quantities that they are unlikely ever to become critical in a war economy. These are calcined gypsum, portland cement and magnesite or magnesium oxy-sulphate cement. The first two, when purchased for industrial consumption, can probably be obtained under contract for less than a cent per pound at many points in the U. S. They are heavier than the magnesite cements but cost less per pound. The latter are commercially sound and available for board manufacture in very limited areas whereas both calcined gypsum and portland cement are manufactured in many factories widely scattered about the country.

It will be noted that three factors must be weighed in deciding upon the choice of the binder and the location of the board plant, namely, the cost of the binder delivered to the factory, the delivered cost of the wood, and the average distance the manufactured board must be shipped to reach the consumer. The proper weighting of each of these factors is not a simple problem in arithmetic, particularly when human factors must also be put into the balance such as the desire of a lumber manufacturer to have a neighboring factory that will take his solid saw mill waste or his low grade logs, or the desire of a cement or gypsum manufacturer to locate a major, steady consumer near his plant. It is, however, not the purpose of the present paper to go into the details of this complex problem of business economics, but rather to discuss the kinds of boards that can be made, how they are made, and their properties and uses. We will explore the various forms in which wood or wood waste may be used, the processes or means for mixing the binders and of forming the boards, the strength, insulating value, fire resistance and durability of products now made, and then will present the results of work recently completed by Elmendorf Research, Inc. aimed at the production of a new type of fire-resistant board.

Long experience in the development of boards of different types has shown that the binder used per square foot of board invariably costs more than the wood. The cost of the latter is seldom as important as the properties that are obtainable with each type of wood waste or fiber. For example, sawdust and shavings from a lumber mill may be available at $5.00 per ton whereas excelsior may cost $50.00 per ton, but this does not mean that sawdust and shavings are necessarily commercially sound materials to use in preference to the excelsior.

Sawdust Concrete

Tests made by various laboratories have shown that combinations of sawdust and portland cement always produce a relatively weak and brittle board. The possibilities of using such a combination as a concrete for farm buildings are, however, frequently mentioned, and so it is well to briefly survey that subject.

Experimental work has been done at the Universities of New Hampshire, Minnesota, and Wisconsin to produce a satisfactory sawdust concrete for floors of barns, as the sawdust concrete has relatively good insulating value and some resilience. If it did not have negating liabilities it would be an ideal floor for barns and poultry houses. Experiments made at the University of Minnesota have shown, however, that such concrete has only about 10 to 20 percent of the strength of normal concrete made with sand and gravel. It lacks abrasive resistance, and sawdust of a number of species when present

may cause long delays in the setting of the cement. Tests made by Elmendorf Research, Inc. showed that this is true of woods containing certain acid or sugar solubles such as oak, redwood, and larch. Considerable cooking or leaching is necessary to obtain normal rates of cement setting when particles of these and some other species are included.

Shavings Bonded With Cement

As the conventional wood shavings are flat chips containing greater fiber length than particles of sawdust, their use in combination with inorganic binders for the manufacture of building slabs or blocks has frequently drawn the attention of inventors. Several years ago a block was offered to the building industry in which wood shavings were used with cement as the binder and vertical holes were provided that were subsequently filled with normal cement mortar to form strong columns for carrying the roof load. Considerable publicity was given to the construction at the time, but the ruthless laws of competition with conventional construction apparently decreed a short life for the project.

A building slab described as a structural insulated roof plank was the subject of a paper presented at a conference called by the Northeastern Wood Utilization Council at Cambridge, Mass. on September 16, 1949. The parent product has apparently had some success in Switzerland and several other foreign countries and its manufacture in this country has been heralded. It is reported to have a density ranging from .43 to .80, and in the form of a hollow slab to have a bending strength of 130 to 170 psi. Its thermal conductivity is given as .75 Btu. per sq. ft. per hr. per inch thickness per deg. F. difference in temperature. It is made basically of conventional wood shavings.

Extensive tests made by Elmendorf Research, Inc. with many forms of wood waste and wood fibers have shown quite conclusively that for maximum strength per pound of raw material the wood shavings should be used in the form of strands of appreciable length in which the botanic fibers are parallel to the strand surfaces throughout their length. In the case of conventional wood shavings coming from a planer the botanic fibers are cut obliquely over most of the cut and their maximum strength has been lost. It is only necessary to break a shaving with the fingers to see the direction of the constituent wood fibers and to realize how weak the shaving is. This weakness is reflected in the relative weakness of boards made of them in comparison with boards made of the same weight of the shaving strands produced by special machinery designed for that purpose. This subject will be considered in more detail toward the latter part of this paper.

Excelsior Fiber Boards

The use of excelsior bonded with inorganic binders for board-like porous slabs is now a well established and growing industry both in this country and abroad.

Slabs of this type are very extensively used in the building industry throughout Europe and to a large extent take the place of insulation and plaster boards made in this country. Germany alone has almost 300 factories producing such a product. Most of the operations are small. The manufacture of excelsior boards is generally carried on in factories that serve a local market, and often may be manned by a working crew of less than 10 men. In such cases there is very little mechanization of manufacture, and the molds are filled by hand. Since the uses of the product are well established little promotional selling is required, and under a price established by the German government the small manufacturer is apparently able to prosper. The largest producer, the Heraklith Co., has two factories turning out about 600,000 sq. ft. of board per day. It is, therefore, comparable in size with a substantial manufacturer of wallboard in the U. S. Its product is being promoted by means of detailed technical literature, and Heraklith slabs are widely sold.

Sizes

Table 1 lists the names of most of the excelsior boards made in the U. S. A. and Canada, and Table 2 lists three well known German products. All the latter are made 50 by 200 cm. in size. The major thickness abroad is 2.5 cm. or about 1 inch. Boards of this thickness weigh about 2.5 lb. per sq. ft. The foreign boards are available in thicknesses ranging from 1.5 to 7.5 cm. In the U. S. the major thickness is also 1 inch, but excelsior slabs are also being made in substantial quantities 2 and 3 inches thick. The weight averages a little over 2.5 lb. per sq. ft. in the 1-inch thickness.

TABLE 1.—BOARDS MADE IN THE U. S. A. AND CANADA

Name of product	Size inches	Wt. lb./sq. ft. 1-inch thick	Bending strength psi.	Thermal cond. Btu/ sq. ft./hr./ in./deg. F.	Coeff. of sound absorption 1-inch
Cementex	32 by 64	3.5	428	—	—
Cemex	48 by 96	2.5	412	.58	.60
Insulrock	32 by 96	2.8	340	—	—
Porex	20 by 80	2.3	—	.47	.60
Rockwood	32 by 48	2.7	364	.64	.60
Sonotherm	32 by 48	2.0	250	.40	.55
Av.		2.6	360	.50	.59

Data from the manufacturers published literature.

TABLE 2.—BOARDS MADE IN GERMANY

Name of product	Size inches	Wt. lb./sq. ft. 1-inch thick	Thermal conductivity B.t.u./sq. ft./ hr./inch/ degree F.	Coeff. of sound absorption 1-inch
Heraklith	20 by 80	2.4	.46	.50
Isodiele	20 by 80	2.2	.47	—
Torfotek	20 by 80	2.2	.49	—
Av.		2.3	.47	.50

Data from the manufacturers published literature or from Report on the German Wood Wool Building Slab Industry (1).

While the foreign boards are all made in one size, having an area of 1 sq. meter, it will be noted that the American boards are made in various sizes ranging from 32 by 48 inches up to 48 by 96 inches, the dimensions generally being some multiple of 16 inches, the standard stud spacing. The weight of the U. S. Board is, on the whole, slightly greater than that of the European products.

Properties

The data brought together in Tables 1 and 2 came from published information but should not be used for exact comparisons of one material with another. While the tests reported were generally made by recognized testing laboratories, we have no evidence that they represent average figures for each manufacturr's product nor that the strength, thermal conductivity and coefficient of sound absoption are always those of boards of the density listed. It must also be borne in mind that the density and the physical properties frequently vary considerably from board to board and in different areas in the same board.

The thermal conductivity of commercially made boards of the excelsior type weighing 2.5 lb. per sq. ft. is about 0.50 Btu. per sq. ft. per hr. per in. per deg. F. which may be compared with 0.35 for structural insulation boards. In view of the fact that the excelsior type of board when used as a plaster base for ceilings is 1.0 inch thick and standard insulation boards are only ½-inch thick, the insulating value of the former exceeds that of the latter. It is because the excelsior boards contribute considerable insulation that they are becoming a standard building material in the European building industry.

In this country excelsior boards are being used to a large extent because they provide accoustical treatment at relatively low cost. The sound absorbing efficiency is determined to a large extent by the fineness of the excelsior used. For the standard slabs made of excelsior fibers ⅛ to $\frac{3}{16}$ inches wide a coefficient of sound absorption of .50 may be expected for boards 1-inch thick weighing 2.5 lb. per sq. ft. When wood wool is used a coefficient of 0.60 should be obtained, and for the higher frequencies of sound waves even higher figures may be expected. The boards are, therefore, not quite as efficient as the better grades of acoustical tile so extensively used in this country for sound absorption for which an efficiency of .75 may be expected, but it should always be borne in mind that equally good acoustical treatment is often obtainable with less efficient materials by simply increasing the wall or ceiling area covered with the sound absorbing material.

Among the other valuable properties of the excelsior type of board made with inorganic binders is its resistance to the spread of fire. Such boards do not support combustion. On the other hand they are not fireproof in the sense of an asbestos board or a brick wall because the organic fibers will slowly decompose in the presence of intense heat.

The coating of inorganic binder surrounding each excelsior strip is resistant to the attack of termites and prevents the growth of fungi so that the excelsior boards are also being sold for their value in resisting insect destruction and decay.

Uses and Competition

While the excelsior slabs now so extensively used in the European building industry are finding many uses in house construction, their major single use is that of a plaster base in ceilings. Abroad they are, however, also being used as a plaster base for walls and as a stucco base in building exteriors. When used as a base for either plaster or stucco, the joints are invariably reinforced with strips of wire netting or expanded metal lightly nailed over the joints before the mortar is applied. For walls the boards may be nailed to wood framing or to furring strips on brick or masonry.

A substantial market also exists abroad for the boards as an under layer in floors, in which case they are generally surfaced with cement mortar or magnesite cement about ½-inch thick. Their strength as a beam is not sufficient to support normal floor loads so that they cannot be used without a supporting structural floor. In the case of roof decks where they are generally 2 to 3 inches thick they have sufficient flexural strength to support snow loads with an adequate factor of safety. For that use the slabs may be surfaced with cement mortar to which built-up roofing is applied, but the roofing is also sometimes bonded directly to the slab.

The use of the excelsior slabs for form lining in concrete work is also advocated where the boards are to remain in place bonded to the concrete and so function as an acoustical treatment in the ceiling or walls of the completed room.

In this country where other types of lower cost plaster bases are available competition has greatly restricted the use of the excelsior boards for ceiling work. Their use as a sheathing material is being advocated and finding considerable application particularly where stucco is to be applied to them. The stucco keys very well to the fibrous open texture. Reinforcing strips must be applied over the joints to prevent cracking.

The boards are finding considerable acceptance in this country when used for interior decoration where both fire-resistance and sound quieting are required as in restaurants and bowling alleys.

The major use developed in this country to date is for roof-decking of industrial buildings. For that use the slabs are generally either 2 or 3 inches thick and the supports may be from 24 to 48 inches apart.

Some unsuccessful attempts have been made in this country to manufacture excelsior boards following European practice. A factory to make a board similar to the eminently successful Heraklith of foreign manufacture was built several years ago in the State of Washington at a location where all raw materials were available in large quantity and at favorable prices, but the largest market turned out to be roof-decking of large buildings, hence in the eastern part of the country. As slabs 2 and 3 inches thick are relatively heavy the shipping costs to the market proved to be an insurmountable handicap in competition with other types of roof-decking, and the large production for which the plant was built was never realized. On the other hand, where less ambitious operations have been started near major markets, they have been a success.

Methods of Manufacture

The manufacture of the excelsior building slabs may be conducted on a very small to a very large scale. For small scale manufacture the excelsior and the binder are mixed manually with elementary equipment and the coated fibers are filled into wood molds by hand. A stack of molds is subjected to pressure and then held under constraint until the binder has set, which may be 24 hours in the case of portland cement. Upon removal of the slabs from the molds they are dried. As the scale of manufacture increases more of the operations are mechanized. Maximum mechanization has been reached in the manufacture of Heraklith where the coated excelsior is spread upon a steel belt and is then carried under light pressure between this belt and a second belt through a long heated tunnel. The magnesia oxy-sulphate binder used sets sufficiently so that upon leaving this tunnel and the constraint of the belts, the slabs may be sent through drying ovens. Upon leaving these they are stacked and cooled, whereupon they are ready for shipment. The labor cost per square foot of board is only about one-third that of a typical separate mold operation, but partly offsetting this economy is the greater amortization charge that must be applied against the production on account of the large capital investment, and the larger administrative overhead.

For maximum speed of setting calcined gypsum is used as the binder, but here too the slab must be kept under light pressure while the gypsum is setting. In one German plant, this is achieved in a continuous belt process in which pressure is maintained by a clamping system and the clamps are automatically released at the end of the operation.

In another plant using portland cement as the binder the molds are stacked and pushed up through a hot "chimney", the weight of the molds providing the necessary compression. Stops between the molds determine the thickness. The fibers are "pickled" before coating with cement. Sufficient set has taken place at the top of the chimney to permit removal of the boards from the molds. The freshly filled molds are added at the bottom, one after another, under hydraulic thrust pushing the load up.

As previously remarked three types of binders are all being successfully used, namely, portland cement, magnesite, and gypsum. The ratio of the binder weight to the weight of the excelsior generally ranges from about 2:1 to 3:1.

No two major manufacturers of excelsior type boards use exactly the same means for mixing the binder with the fibers, an operation that must be carried out mechanically and that is not as readily accomplished as mixing ordinary aggregates with cement and water and sometimes shows the application of considerable mechanical ingenuity.

When portland cement is used as the binder, the fibers are often "mineralized" to improve the bond, or to increase the rate of setting of the cement, or to improve the fire-resistance. In the method developed by the author, the fibers are first treated with sodium silicate and then with calcium chloride to precipitate calcium silicate on the fibers. The water soluble sodium chloride which is a product of the reaction is then washed off.[1]

The type of binder to use is often the subject of considerable discussion. In this country most commercial products are made with portland cement, whereas abroad magnesia oxy-sulphate cement comes first, portland cement next, and gypsum third. The choice of binder is determined by its availability and price and the market for which the board is intended. A manufacturer of gypsum would obviously plan his operation on the basis of using calcined gypsum.

Development of a Low Cost Plaster Base

The standard 1-inch thickness of cement-excelsior board can obviously not compete on any substantial scale with the plaster board and insulation board lath now standard in the building industry of this country. An experimental study conducted by Elmendorf Research, Inc. over a period of years aimed

[1] U. S. Patent No. 2,377,484.

at solving the economics of this problem has established certain basic requirements that must be met as follows:

1. The manufacturing cost may not deviate widely from the manufacturing cost of conventional paper-faced gypsum lath. We have established $25.00 per M as the maximum production cost. This means that some fiber lower in cost than excelsior must become available, and secondly, that the board be made by a manufacturer of gypsum or portland cement or under some advantageous contract with such a manufacturer. We have, therefore, bent our own efforts at producing a new low cost fiber and have now developed a machine which converts solid wood waste, such as saw mill slabs into the desired fibers at a cost of about 1/3 that of excelsior. We are referring to these fibers as A-fibers.

2. The thickness may not deviate widely from 3/8-inch, and the board must be comparable with regular plaster board lath in stiffness and strength. Table 3 shows the results of the tests made on the lath we have developed using our A-fibers and portland cement as the binder. Our laboratory lath is here referred to as Pyro-Lath on account of its fire-resistance. The tests were made on specimens 6 inches wide, supported on a span of 10 inches and tested as simple beams.

TABLE 3

Material	Wt. lb. per sq. ft.	Thickness inches	Max. load lb.	Stiffness load per 0.1 inch deflection
3/8-in. Pyro-lath	1.27	0.40	52	26
3/8-in. Pyro-lath	1.22	0.41	57	23
1/4-in. gypsum lath, paper faced	1.26	0.25	36	14
3/8-in. gypsum lath, paper faced	1.60	0.38	92	57

The strength and stiffness of Pyro-Lath therefore lies between that of 1/4-inch and 3/8-inch gypsum board lath and may be regarded as satisfactory.

3. The plaster must not crack at the board joints and the metal reinforcement used with insulation board lath must be eliminated on account of cost. Tests on this matter are in progress.

4. Complete mechanization of board formation must be achieved.

5. The lath must have a market within a radius of not more than 300 miles from the factory adequate to absorb the production of the plant. The plant must be able to turn out the lath at a production rate of 100,000 sq. ft. per day at the stipulated maximum cost of $25.00. This in our opinion is possible.

Development of a Low Cost Fire-Resistant Wall Board

The development of the machine for producing A-fibers out of solid wood sawmill waste as well as out of cordwood has opened up new possibilities in the manufacture of gypsum wallboards by eliminating the paper faces. This subject has been extensively explored by Elmendorf Research, Inc. and a great deal of research work has now been done to meet the requirements set.

Tests have shown that the strength properties of conventional gypsum wallboard across the machine direction are substantially below those in the machine direction, and since it is customary to apply the boards with the machine direction parallel to the studding the strength across the machine direction is the most important. The new board should be substantially stronger across the machine direction than conventional gypsum board.

While conventional gypsum boards are 3/8-inch and 1/2-inch thick, it would be desirable to have a board of comparable cost 3/4-inch thick, to conform to standard lath and plaster thickness. The board should also be able to absorb a blow which would break ordinary gypsum board, that is, it should be tougher than the latter. It should be applied, if possible, with nails having smaller heads so that the surface is not disfigured, and it should be more resistant to fire. That these requirements have been met will be seen from the following test data:

Numerous boards have been made in our laboratory in both 1/2-inch and 3/4-inch thickness using both gypsum and portland cement as the matrix with A-fibers. These boards are made under some pressure so that they are substantially solid and they differ widely therefore from the excelsior boards in both structure and density. The surface is smooth, flat, and hard.

Flexural strength tests are made on specimens 5-inches wide supported on a span of 10-inches with a center load, and the test is continued until there is practically no residual strength in the specimen. The slope of the load-deflection curve up to the proportional limit measures the stiffness, which is given in Table 4 as the load which will bend the

TABLE 4

Product	Wt. lb. per sq. ft.	Thickness inches	Max. load lb.	Stiffness lb. per .01 inch defl.	Toughness in.-lb.
1/2-in. gypsum A-fiber board	3.00	0.515	112	33.0	43.7
1/2-in. commercial gypsum board	2.30	0.470	30	8.0	3.3
1/2-in. commercial insulation board	0.77	0.490	21.5	1.0	9.8

specimen 1/100-inch. The area under the curve represents the work done to completely break the specimen. It is a measure of the toughness of the specimen. The data in the table are for tests made across the machine direction. In the particular insulation board tested there is little difference in the machine and across the machine direction, but the gypsum board is substantially stronger in the machine direction. As the boards should be tested to reflect their strength in use, comparisons should be made of the across-the-machine strengths.

There is no difference in the strength of the A-fiber board in the two directions. The tests show that it is several times as strong as commercial gypsum and insulation boards. The same holds for stiffness and toughness. The reinforcing imparted to the gypsum matrix by the A-fibers is particularly reflected in the toughness. When the maximum load of the paper-faced commercial gypsum board is reached it fails abruptly and completely, whereas the A-fiber board is more nearly comparable with plywood in that it still has a lot of residual strength after the maximum load has been reached.

By a small increase in the amount of material and a slight reduction in the density a ¾-inch gypsum A-fiber board can be made. This board also has smooth hard gypsum faces. It weighs 3.2 lb. per sq. ft. Table 5 compares the strength properties of this board with those of ½-inch commercial plaster board in the two directions.

TABLE 5

Product	Wt. lb. per sq. ft.	Thickness in.	Max. load lb.	Stiffness lb./.01 in. defl.	Toughness in.-lb.
¾-in. gypsum A-fiber board	3.2	0.75	138	54.0	45.0
½-in. commercial gypsum board in mach., dir.	2.3	0.47	97	12.5	11.2
½-in. commercial gypsum board across mach., dir.	2.3	0.47	30	8.0	3.4

The superiority in the stiffness and toughness of the gypsum A-fiber board is again striking. The greater weight is due to the gypsum facing which is continuous and smooth and eliminates the need for subsequent plastering.

While the A-fibers are basically shavings, they are long narrow shavings in which the botanic wood fibers are parallel to the surface of the shaving or strand throughout its length. The length may range from about 1 to 4 inches and they are about 1/100-inch thick. They retain substantially the full tensile strength of the wood whereas in ordinary planer shavings the botanic wood fibers are cut through at an angle and the high tensile strength of the wood is lost. The A-fiber machine lends itself to the reduction of saw mill slabs, end trim and cord wood, all cut green.

While fire tests are limited at this time to laboratory specimens, the following test indicates some superiority in fire resistance of the gypsum A-fiber board in comparison with commercial paper faced gypsum boads of about the same thickness. Specimens 3-inches wide are supported on a 5-inch span with a small center load. A broad bunsen burner is allowed to play on the bottom of the specimen directly under the load. The time required for the specimen to collapse is noted. In this test the gypsum A-fiber boards hold up for about 13 minutes whereas the commercial gypsum boards fail in less than 4 minutes. After the paper face of the latter has been burnt away the core begins to crack permitting the opposite side to char. No such cracking takes place with the reinforcement provided by the A-fibers.

Tests were made to determine the resistance of the boards to the pull of nails, by measuring the force required to pull a nail down into the board to submerge the nail head. The resultant pull for two types of nails is given in Table 6.

TABLE 6

Product	Pull in pounds: 4d box nail = 0.21 in.	Pull in pounds: Cadmium coated nail = .095 in.
Gypsum A-fiber board	302	86
Commercial gypsum board	83	35

It would appear from this table that smaller headed nails may be used for applying the A-fiber boards to wood framing, thereby reducing the tendency for the nails to disfigure the board for interior finish.

Another important potentiality may be mentioned regarding the use of the gypsum A-fiber boards. By furnishing the boards with shiplap edges these edges may be glued on the job and a continuous crack free plaster wall obtained. It is only necessary to fill the narrow V-crack at the joint with a gypsum filler to obtain a continuous plaster wall in which the plaster has been applied in the factory. Heretofore dry-wall construction in plaster has not been possible.

One further comment should be added. The cost of the A-fibers per ton will be only about 1/6 as much as the paper of the present paper faced plaster board. The combined materials cost of the A-fiber board will therefore be appreciably less than the materials cost of the latter. The new board also lends itself to continuous formation so that the manufacture can be completely mechanized.

Some of the products and processes described in this paper are covered by patents or patent applications. No attempt has been made here to include an analysis of the patent art.

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Discussion

Mr. X: Why isn't a larger percentage of small pieces of sawmill waste used in paper making?

Mr. Elmendorf: Small pieces or blocks as well as sawmill slabs can be converted into our fibers. The same blocks cannot very readily be reduced to chips for making paper.

Roswell D. Carpenter (Southern Forest Experiment Station): Waste studies conducted in 1948 and 1949 at 17 southern pine sawmills, in cooperation with the Southern Kraft Division of the International Paper Co. showed that 94 percent of all heavy waste (slabs, edgings and end trims) would chip satisfactorily in present-day paper mill chippers. The remaining 6 percent was composed of ribbon-like pieces of edging, which wound up and slivered in the chipper, and pieces of end trim less than one foot long which turn down sidewise in the throat of the chipper and shingle off in long slivers. All waste accumulated during these studies was analysed for suitability for chipping in standard paper mill chippers.

H. E. Murphy (Tennessee Valley Authority): Are southern pine, gum, and poplar suitable species; and how much waste is necessary to support a plant?

Mr. Elmendorf: Southern pine and poplar are readily converted to fibers, but gum fibers tend to be brittle. Two tons of solid wood waste per day are adequate for a small commercial operation.

Mr. X: Does cross grain cause any difficulties?

Mr. Elmendorf: Cross grain in the blocks, if severe, will reduce the fiber strength, but such fibers are broken into shorter lengths in the operation of mixing the binder so cross grain is no serious liability.

Effect of Storage of Slash Pine Pulpwood on Sulfate and Groundwood Pulp Quality

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The loss in yield of sulfate and groundwood pulps on a wood volume basis is proportional to the decrease in density of the pulpwood during storage, fall-cut wood stored under the conditions of the experiment reported should be used within 5 months to avoid measurable losses in the strength of the sulfate pulp. The principal effect of storage on the groundwood pulp is a decrease in brightness.

Introduction

Pulpwood storage is claiming increased attention as an important factor in the operating efficiency of pulp mills and the quality of their products. Although the possible ill effects of extended storage times and poor storage practice have been recognized, specific information about the effects of storage of pulpwood upon the yield and quality of pulp is scanty.

The practice and requirements for pulpwood storage vary, of course, according to region, species, and process. In the South, general practice has been to store for as short a time as possible, usually 3 months at the most.[2] Extended storage has led to obvious decay, and it is widely believed that the decayed wood gives pulps of seriously lower quality.[3]

It was the purpose of this investigation to determine the effect of 12 months' storage of southern pine in a pulp mill yard on the yield and quality of sulfate and groundwood pulps made in laboratory-scale experiments. The wood represented part of that used in an extensive storage study which included unpeeled and peeled slash and loblolly pines cut in July and October 1948 and May 1949.[4] The pulping experiments were made on slash pine cut in October 1948. Tests were made on unpeeled and peeled wood in the green condition and after storage in open piles in the yard of a pulp mill in Bogalusa, La., for periods of 4, 6, 9, and 12 months.

A general literature review on various aspects of pulpwood decay and its effect on pulp yield and quality was recently reported by Pascoe and Scheffer[5] in connection with an investigation of the effect of the deterioration of jack pine in storage on sulfate pulp and paper quality. The experiments of Pascoe and Scheffer were conducted in a way similar to those reported here on slash pine, and involved the same principal decay organism, *Peniophora gigantea.* The cited work on jack pine showed appreciable reduction in the density of the wood with storage over two summers in a northern pulp mill yard, losses in sulfate pulp and paper strength from rough-stored wood being particularly serious. Keaton and Gillespie reported recently on operational difficulties presented by storage of southern pine pulpwood and mentioned appreciable loss in pulp strength as a result of storage.[3]

Experimental Part

The Wood

The shipments of unpeeled and peeled wood received at the Forest Products Laboratory at the end of each storage period were comprised of 200 bolt sections representing one-half of each of 50 pulpwood logs for both types of wood. Each lot consisted of 50 end sections approximately 10 inches long and 50 inside sections approximately 20 inches long. This material had been dipped in a sap stain control chemical before shipment. Representative samples were sawed into bolts 6 inches long for the groundwood pulping experiments and converted into standard $\frac{5}{8}$-inch chips for the sulfate pulping experiments. The chips were screened to remove oversized and under-sized material. A sample of the chips was analyzed for chemical composition (Table 1).

Sulfate Pulping

The sulfate pulping was conducted in steam-jacketed, spherical, rotary autoclaves with a capacity of 0.5 cubic foot. The pulping conditions were de-

[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2] Anonymous. 1949. Protection with Chemicals. Pulp and Paper 23, No. 11:78–80.

[3] Keaton, H. L. and Gillespie, W. F. 1950. Effect of Storage of Southern Pine on Pulp Yield and Quality. Paper Mill News 73, No. 45:14.

[4] Lindgren, R. M. 1951. Deterioration of Southern Pine Pulpwood as Affected by Length and Time of Storage. Forest Products Research Society, Proceedings, 1951.

[5] Pascoe, T. A. and Scheffer, T. C. 1950. Jack Pine Pulpwood Deterioration in Yard Storage. Paper Trade J. 131, No. 2:16–18, 20–21.

TABLE 1.—DENSITY, MOISTURE CONTENT AND CHEMICAL ANALYSES OF SLASH PINE WOOD AND CHEMICAL ANALYSIS OF SULFATE PULPS FOR VARIOUS TIMES OF STORAGE

Shipment of wood numbers or digestion number of	Duration of storage	Moisture content of wood[1]	Density of wood[2]	Chemical analyses[3]								
				Holocellulose	Alpha cellulose	Lignin	Total pentosans	Solubility in— Alcohol benzene	Ether	1 percent sodium hydroxide	Hot water	Ash
	Months	Percent	Lb. per cu. ft.	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Unpeeled wood												
2795	0	53.1	30.8	62.8	48.5	27.6	8.4	2.6	2.4	12.7	2.7	0.1
2836	4	52.1	30.0	65.5	49.6	27.9	8.7	2.4	1.7	10.8	2.1	.2
2863	6	50.7	29.0	66.5	47.2	28.3	8.0	2.6	2.3	11.8	2.4	.3
2900	9	47.3	27.7	68.1	49.2	28.0	8.3	1.8	1.7	13.1	3.5	.4
2946	12	46.0	25.8	65.2	45.9	28.2	8.0	4.1	2.2	14.3	4.1	.5
Peeled wood												
2837	4	26.8	29.0	63.4	49.1	28.1	8.7	3.1	1.9	11.3	2.6	.2
2864	6	23.4	29.2	66.4	48.0	27.7	8.3	3.9	2.6	14.3	4.1	.2
2899	9	20.2	28.5	66.9	48.0	27.9	8.1	2.9	1.9	12.8	3.2	.4
2945	12	18.4	28.6	66.0	49.3	28.0	7.6	2.9	1.3	12.4	3.0	.2
Sulfate pulp from unpeeled wood												
2055–6x	0	—	—	95.9	80.2	4.6	8.0	—	—	—	—	—
2187–8x	9	—	—	95.0	80.8	5.2	8.3	—	—	—	—	—
2217–8x	12	—	—	96.2	79.4	5.5	8.2	—	—	—	—	—
Sulfate pulp from peeled wood												
2189–90x	9	—	—	94.7	82.7	5.0	8.2	—	—	—	—	—
2213–4x	12	—	—	94.9	80.1	5.5	7.7	—	—	—	—	—

[1] Based on total weight of wood and moisture.
[2] Moisture-free weight per green volume.
[3] Based on moisture-free material.

signed to produce strong sulfate or kraft-type pulp. These conditions included the use of 15.6 percent of total chemical as sodium oxide, based on the weight of the wood. The autoclaves were heated indirectly, and no spent or black liquor was used. The calculations of the volumes and concentrations included the moisture in the chips. The other pulping conditions are given in Table 2. The pulps were tested for strength and chemical composition by standard methods.

Groundwood Pulping

The semicommercial experimental grinder at the Forest Products Laboratory was used for the groundwood pulping experiments. A single pulpstone faced with 60-grit aluminum oxide abrasive was used for this work, so that the stone surface for all the runs was the same. Except for variations in pressure, other operating conditions were also identical for all the experiments. Grinder runs were made on each sample of wood at three different grinding pressures in order to obtain pulps having a range of properties. The stone surface was fairly sharp. Though a duller surface might have been more suitable, the pulps obtained were within the practical range of quality and capable of evaluation of the effects of storage. The pulps were tested for strength and other properties by conventional methods.

TABLE 2.—SULFATE PULPING OF SLASH PINE PULPWOOD AFTER VARIOUS PERIODS OF STORAGE

Wood				Cooking[1] and yield data					Bleach test data		
						Yield of pulp (moisture-free)			Brightness		
Type represented	Shipment No.	Storage period	Digestion No.	Chemicals consumed Percent	Black liquor density at 15° C. °B.	Per 100 pounds of moisture-free wood: Screened Pounds	Per 100 pounds of moisture-free wood: Screenings Pounds	Per cubic foot of solid wood (screened pulp) Pounds	Unbleached pulp Percent	Pulp bleached with 8.75 percent chlorine Percent	Permanganate No.
Rough	2,795	0	2055X, 2056X	80.4	10.6	45.9	0.3	14.1	23.1	40.1	23.9
Do	2,836	4	2128X, 2129X	81.3	10.8	46.3	.4	13.9	22.8	49.1	24.3
Do	2,863	6	2154X, 2155X	81.1	10.7	45.1	.2	13.1	22.8	46.2	24.2
Do	2,900	9	2187X, 2188X	82.7	10.7	46.4	.4	12.9	22.2	48.6	24.5
Do	2,946	12	2217X, 2218X	85.3	10.6	45.4	.5	11.7	22.9	45.0	25.9
Peeled	2,798	0	2065–2067X	81.3	10.7	46.3	.4	14.3	22.2	38.4	25.9
Do	2,837	4	2126X, 2127X	81.3	11.0	46.4	.3	13.5	21.3	40.4	25.6
Do	2,864	6	2152X, 2153X	82.3	10.7	45.2	.8	13.2	22.2	46.5	25.9
Do	2,899	9	2189X, 2190X	82.7	10.6	46.8	.5	13.3	22.5	48.6	24.8
Do	2,945	12	2213X, 2214X	82.0	10.6	47.1	.3	13.5	22.5	48.8	25.1

[1] The cooking conditions other than those tabulated were as follows:

Weight of moisture-free wood	pounds	4.0
Maximum temperature	°C.	170.0
Temperature increase period	hours	1.5
Duration at maximum temperature	hours	1.5
Initial chemical concentration (calculated as sodium oxide)	gm. per liter	39.1
Sulfidity (based on active alkali)	percent	30.0
Sodium hydroxide	percent	14.1
Sodium sulfide	percent	5.9
Liquor-wood ratio		4.0

Effect of Storage on Properties and Chemical Composition of the Wood

The changes in the properties of the unpeeled and peeled slash pine in storage over a period of 12 months are described in detail elsewhere.[4] Briefly, the peeled wood showed a small amount of decay after 4 months of wintertime storage, with a resultant drop in density of 3 percent. The wood dried nearly to the fiber saturation point in this time. This dry wood therefore deteriorated only slightly on continued exposure because the moisture content was too low to support fungus growth. The loss in density after the year's storage was about 6 percent. The unpeeled wood, on the other hand, exhibited a steady increase in amount of decay and a decrease in density with increase in storage time. In the 12 months' storage the density of this wood decreased approximately 14 percent. The wood, furthermore, had retained most of its moisture after the year's storage, and decay would be expected to continue unabated during further storage.

The loss in wood substance shown by the decrease in density comprised losses in all the major constituents of the wood, lignin, alpha cellulose, and hemicelluloses (Table 1, Fig. 1). The lignin

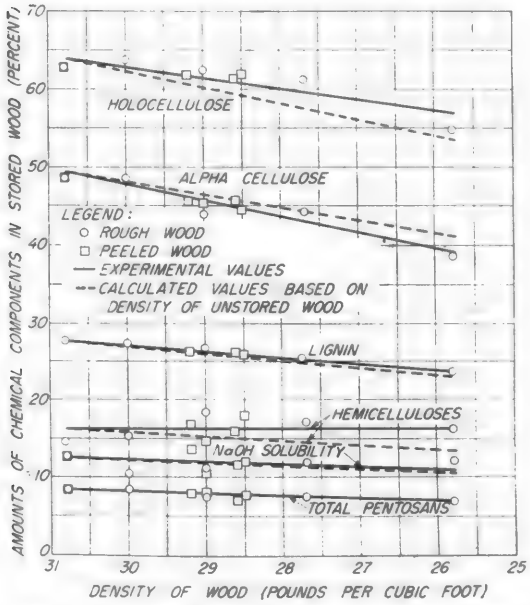


Fig. 1.—Relation between chemical components and density of slash pine pulpwood after storage.

yield decreased at about the same rate as the density, but the alpha, or resistant, cellulose was apparently degraded at a greater rate than this (Fig. 1). A part of the degraded alpha cellulose appeared to be in the form of hemicelluloses. This is indicated by the facts (a) that the holocellulose loss is less in proportion than the decrease in density, and (b) that the hemicellulose yield (difference between holocellulose and alpha cellulose yields) does not change with decreasing density. Those hemicelluloses, in the form of either pentosans or materials soluble in 1 percent sodium hydroxide, however, suffered losses in proportion to the loss in weight of the wood.

Though it is quite common for the amount of material soluble in weak alkali solution to increase with decay, no appreciable change was found in the slash pine after the wood had decayed considerably. This lack of change has also been noted with other species and decay organisms in other tests at the Forest Products Laboratory.[6, 7] Evidently the chemical character of the reaction products obtained in degradation of the cellulosic components of the wood is dependent on the species of wood, the decay organism, and the conditions for the decay action.

That chemical changes other than those caused by decay occur in the wood was shown by the decrease in the ether solubility value with storage. The trend was observed in both the wet unpeeled wood and the dry peeled wood. In neither type of wood, however, was any trend toward change observed with respect to the material soluble in alcohol-benzene.

The main decay organism found in the wood, *Peniophora gigantea,* is a type intermediate between major groups of fungi that produce white and brown rots. The intermediate character of this fungus is demonstrated by the fact the losses of both lignin and carbohydrates are nearly in proportion to the total loss in wood substances. Because of this relatively nonselective attack, the chemical analyses of the various wood samples did not differ in any striking respect.

Effect of Storage on Pulping Characteristics, Pulp Yield, and Quality

Sulfate Pulping Characteristics

All wood used in the exposure tests was pulped under identical conditions. Only small differences were found in pulping characteristics (Table 2).

There was a definite but small increase in the amount of pulping chemical consumed with increase in the deterioration of the wood as evidenced by density loss (Fig. 2). It is indicated that a higher ratio of alkali was consumed in reacting with carbohydrates in the deteriorated wood than in the sound wood, since pulp yield (per unit weight of wood) was unchanged and the lignin content of the pulp was actually increased slightly (Fig. 2). Possible reasons for the increased alkali consumption are the formation of acid groups by the decay reactions and the production of alkali-soluble, shorter-chain car-

[6] Forest Products Laboratory. Pulping of Green-cut and Insect-killed Lodgepole Pine. Forest Products Laboratory Report No. R 1732.

[7] Martin, J. S. 1949. Sulfate Pulping of Logging and Sawmill Wastes of Old-growth Douglas-fir and Certain Associated Species. TAPPI 32, No. 12:534–539.

bohydrates by degradation of resistant cellulose in decayed wood. This is indicated by the analyses of the woods.

As mentioned above, percentage yield of pulp did not vary with change in density (Table 2). Therefore pulp yield declined with storage time in the same proportion as did wood density (Fig. 2).

Chemical Composition and Brightness of Sulfate Pulps

The trend toward less thorough pulping of the more badly deteriorated wood, as shown by the lignin content of the pulps was confirmed by the trend of permanganate numbers of the unpeeled wood, but an opposite trend was obtained for the pulps from the peeled wood (Fig. 2). Trends toward increase in lignin content and permanganate number as wood deteriorated had also been observed in similar experiments with jack pine.

Another effect of time of storage was the increase in brightness of the bleached pulps (single-stage bleach test) (Table 2). The lignin content of the

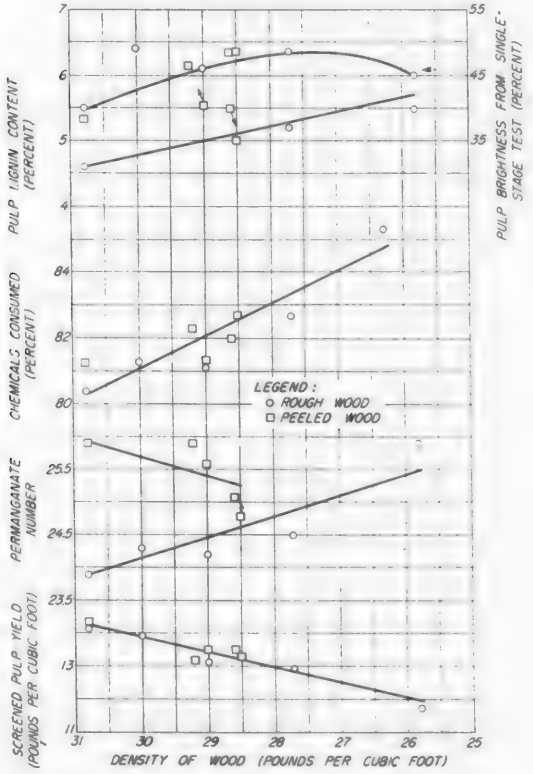


Fig. 2.—Relation between yield, permanganate number, and lignin content of sulfate pulps and density of stored slash pine pulpwood.

pulps and the presence of blue stain in the stored wood would lead one to expect the opposite. The brightness of the unbleached pulps, on the other hand, was unchanged by wood storage.

Amounts of holocellulose, alpha cellulose, and pentosans did not change during storage.

Strength Properties of Sulfate Pulps

The sulfate pulps made from the stored woods had lower strength properties (except tensile strength) than those made from the green woods roughly in proportion to the amount of deterioration (Table 3, Fig. 3). Although the test values

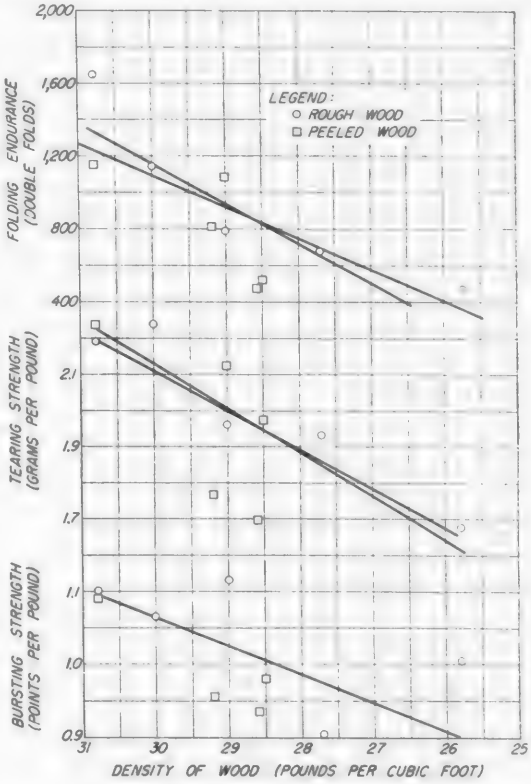


Fig. 3.—Relation between strength properties of slash pine sulfate pulps and wood density after storage.

are variable, trends toward lower bursting and tearing strength and folding endurance were apparent with decrease in wood density. The maximum losses in strength for the pulp from the wood of lowest density were approximately 20 percent in bursting strength, 25 percent in tearing strength, and 75 percent in folding endurance. Tensile strength, on the other hand, did not change significantly during storage of the wood. This unusual stability of the tensile strength of pulps made from decaying wood was also noted with the jack pine previously mentioned that had been attacked by the same fungus.

The maximum losses noted for bursting and tearing strength and folding endurance are considered to be serious. It is estimated that fall-cut wood stored under the conditions of this experiment should be used within 5 months, to avoid unreasonable losses in pulp strength.

TABLE 3.—STRENGTH PROPERTIES OF SULFATE PULPS MADE FROM SLASH PINE AFTER VARIOUS PERIODS OF STORAGE

Interpolated test-beater strength data[1] on unbleached pulp

Wood			Duration of beating to freeness, of[2]		Bursting strength at freeness, of[2]		Tearing strength at freeness, of[2]		Tensile strength, folding breaking length at freeness, of[2]			Density at freeness, of[2]	
Type represented	Storage time	Digestion No.	450 cc.	250 cc.	450 cc.	250 cc.	450 cc.	250 cc.	450 cc.	250 cc.	450 cc.	450 cc.	250 cc.
					Pt. per lb. per rm.	Pt. per lb. per rm.	Gm. per lb. per rm.	Gm. per lb. per rm.	Meters	Meters	Double folds	Double folds	Gm. per cc.	Gm. per cc.
	Mo.		Min.	Min.										
Rough	0	2055X, 2056X	55	71	1.04	1.16	2.31	2.07	6,800	7,400	1,425	1,875	0.68	0.70
Do	4	2128X, 2129X	52	68	1.00	1.13	2.35	2.05	7,300	7,700	925	1,350	.58	.62
Do	6	2154X, 2155X	46	61	1.05	1.18	2.08	1.84	7,400	8,200	675	900	.63	.71
Do	9	2182X, 2183X	49	68	.88	.93	2.03	1.73	6,800	7,900	550	800	.67	.62
Do	12	2217X, 2218X	38	56	.93	1.08	1.76	1.59	6,600	7,700	390	550	.64	.72
Peeled	0	2065–2067X	45	64	1.04	1.14	2.4	2.07	6,900	7,100	950	1,350	.65	.68
Do	4	2126X, 2127X	56	74	1.06	1.19	2.24	2.01	6,600	7,400	900	1,260	.61	.69
Do	6	2152X, 2153X	43	58	.91	1.00	1.86	1.67	6,800	7,600	625	1,000	.67	.74
Do	9	2189X, 2190X	49	66	.95	1.01	2.10	1.85	6,700	7,100	425	620	.62	.68
Do	12	2213X, 2214X	37	54	.87	1.00	1.81	1.58	6,300	7,200	400	540	.64	.68

[1]Test sheets conditioned and tested at 23° C. and 50 percent relative humidity; ream size of 500 sheets each 25 by 40 inches.
[2]Canadian standard.

Because the chemical composition of the pulps remained unchanged with deterioration of the wood, the loss in strength of the pulps could not be related to their over-all chemical composition. Nor did the dispersed viscosity of the unbleached pulps change with deterioration of the wood. Thus, the loss in pulp strength likewise could not be related to a change in the degree of polymerization of the cellulose as a result of the action of the decay organisms.

Grinding Characteristics and Properties of Groundwood Pulp

The data on grinding characteristics and properties of the groundwood pulps are presented in Table 4. The pulp made from the peeled wood declined slightly in Schopper–Riegler freeness with longer storage. This decrease in freeness might have been caused by the decrease in moisture content of the peeled wood. In other work it has been found that a decrease in the moisture content of southern pine resulted in lowered freeness of the groundwood pulp but had no effect on strength.

One of the principal effects of storage was to reduce the brightness of the pulp. The average brightness of the pulps made from the unpeeled wood dropped 1 percentage point in 4 months of storage, 4.5 percentage points in 6 months, and 8 percentage points in 9 and 12 months. The greatest reduction occurred during the summer months of storage. For the peeled wood, most of the decrease came on the other hand, in the first 4 months (4.2 percentage points), while the losses during 6, 9, and 12 months were 5.5, 6.3, and 6.2 percentage points, respectively.

The bursting and tearing strength of the groundwood pulps did not change much throughout the storage; but after the fourth month for the peeled wood and the sixth month for the unpeeled wood there was a marked increase in tensile strength with storage time.

In these experiments no important differences were noted in the rate of grinding, energy consumption, or fiber length distribution between the green wood and the stored wood. The yield of pulp per cord would, of course, be lowered by the losses in density that occurred in the wood during storage.

Summary

Slash pine (*Pinus caribaea*) pulpwood cut in October 1948 was stored both unpeeled (rough) and peeled in the wood yard of a southern pulp mill for periods of 4, 6, 9, and 12 months. Representative samples of wood were tested at the end of each storage period for amount of decay, density, chemical composition and other properties, after which they were pulped by the sulfate and groundwood processes.

The peeled wood contained a considerable amount of decay and had undergone a small decrease in density after 4 months' storage, but it deteriorated

TABLE 4.—GROUNDWOOD PULPING OF SLASH PINE AFTER VARIOUS PERIOD

Wood				Grinding data[1]				Tests on pulp		
								Freeness		
Length of storage	Shipment No.	Grinder run No.	Dryness of wood	Pressure of wood on stone[2]	Grinding rate of moisture-free wood[3]	Power input[3]	Energy consumed per ton moisture-free wood	Schopper-Riegler	Canadian standard	Retained on 24-me
Mo.			Percent	Lb. per sq. in.	Tons per 24 hr.	Hp.	Hp.-days	Cc.	Cc.	Perce
										Rough wood
0	2,798	757	52.7	15	0.90	49	54	372	103	4.1
0	2,798	756	52.7	20	1.32	57	43	437	120	3.7
0	2,798	755	52.7	25	2.22	78	35	470	150	5.3
4	2,836	764	52.1	10	.68	45	66	275	60	3.8
4	2,836	762	52.1	15	.84	48	57	315	80	4.2
4	2,836	763	52.1	20	1.46	62	43	405	130	5.9
6	2,863	792	59.9	10	.61	40	66	282	50	2.5
6	2,863	790	58.8	15	1.03	47	46	327	88	4.4
6	2,863	791	58.4	20	1.40	60	43	382	128	4.5
9	2,900	819	58.9	10	.60	38	62	272	70	3.3
9	2,900	818	58.9	15	.93	47	50	350	100	3.9
9	2,900	817	58.9	20	1.42	59	41	422	137	3.9
12	2,946	832	55.0	10	.55	35	64	310	83	2.2
12	2,946	830	55.0	15	.72	42	58	313	92	2.7
12	2,946	831	55.0	20	1.76	71	40	400	148	3.3
										Peeled wood
0	2,798	757	52.7	15	.90	49	54	372	103	4.1
0	2,798	756	52.7	20	1.32	57	43	437	120	3.7
0	2,798	755	52.7	25	2.22	78	35	470	150	5.3
4	2,837	767	77.1	10	.70	44	63	265	50	3.3
4	2,837	766	77.1	15	1.26	56	44	405	90	3.5
4	2,837	765	77.1	20	1.88	67	36	435	130	3.5
6	2,864	795	84.6	10	.60	43	72	237	37	1.5
6	2,864	793	84.6	15	.90	49	54	297	73	3.1
6	2,864	794	84.6	20	1.31	52	39	333	92	2.5
9	2,899	823	82.5	10	.55	38	68	298	80	3.3
9	2,899	821	82.5	15	.81	47	58	310	80	4.1
9	2,899	822	82.5	20	1.25	60	48	367	103	5.1
12	2,945	835	81.8	10	.47	34	72	347	91	2.5
12	2,945	834	81.8	15	.75	42	56	372	102	2.5
12	2,945	833	81.8	20	1.17	58	50	360	108	2.5

[1]The pulpstone used in this work was composed of an average 60 grit, aluminum oxide abrasive. It h
service 42 hours before starting these experiments. The stone surface was considered to be fairly sharp. A
simultaneously. The pit temperature was 165° F., and the consistency of the pulp in the grinder pit range
[2]The basis weight of the test sheets was 115 pounds per ream of 500 sheets 25 by 40 inches in size.
[3]The total thrust of the pressure foot (determined by calibration of the cylinder pressure) divided by t
[4]Per square foot of wood-stone contact area.
[5]Calculated from amounts retained on 24-, 42-, 80- and 150-mesh screens and that passing through th

ERIODS OF STORAGE IN THE ROUGH AND IN THE PEELED CONDITION

n pulp suspension

Screen analysis			Properties of pulp test sheets[2]					
					Tensile			
Retained on 24-mesh	Passing through 150-mesh	Fiber length index[3]	Bursting Pt. per lb. per rm.	Tearing Gm. per lb. per rm.	Lb. per sq. in.	Breaking length	Density Gm. per cc.	Brightness
Percent	Percent					Meters		Percent
wood								
4.1	49.5	0.084	0.14	0.47	877	1,540	0.40	56.5
3.7	46.5	.085	.13	.43	749	1,420	.37	56.3
5.3	39.4	.097	.08	.42	549	1,100	.35	55.5
3.8	52.8	.081	.17	.65	1,008	1,860	.38	56.1
4.2	47.9	.087	.14	.51	801	1,520	.37	56.2
5.9	43.5	.092	.09	.45	580	1,235	.33	53.0
2.5	54.8	.079	.17	.44	1,270	2,180	.41	53.3
4.4	51.9	.083	.11	.43	755	1,435	.37	51.3
4.5	49.2	.086	.10	.39	632	1,235	.36	50.3
3.3	52.1	.082	.18	.50	1,320	2,260	.41	49.2
3.9	49.5	.085	.15	.45	1,040	1,930	.38	47.7
3.9	50.5	.084	——	.42	668	1,300	.36	46.4
2.2	51.2	.082	.17	.53	1,113	1,960	.40	49.3
2.7	49.9	.084	.17	.55	1,250	2,250	.39	48.0
3.3	47.0	.088	.13	.46	922	1,750	.37	47.0
wood								
4.1	49.5	.084	.14	.47	877	1,540	.40	56.5
3.7	46.5	.085	.13	.43	749	1,420	.37	56.3
5.3	39.4	.097	.08	.42	549	1,100	.35	55.5
3.3	55.0	.079	.19	.40	1,180	2,070	.40	52.8
3.0	52.1	.081	.10	.37	622	1,250	.35	51.7
3.4	49.6	.084	.07	.32	479	1,020	.33	51.3
1.9	53.7	.079	.17	.47	1,220	2,150	.40	51.4
3.7	51.7	.082	.13	.40	906	1,635	.39	50.7
2.5	51.1	——	.10	.39	602	1,175	.36	49.6
3.9	51.2	.083	.20	.50	1,438	2,350	.43	50.2
4.5	44.3	.091	.17	.48	1,108	2,000	.39	50.1
5.1	48.0	.087	.14	.46	938	1,730	.38	49.1
2.4	48.1	.085	.16	.49	1,073	1,885	.40	50.6
2.2	47.7	.086	.15	.46	1,050	1,845	.40	49.7
2.2	50.5	.083	.15	.47	976	1,805	.38	49.5

It had been dressed with 10-cut, 1½-inch-lead, spiral and 14-point diamond burrs, and had been in rp. A peripheral speed of 3,120 feet per minute was used. Pressure was applied in the three pockets ranged from 3.0 to 4.3 percent. The stone immersion was 9 inches.

e.

l by the area (96 square inches) represented by the product of the pocket width and the wood length

gh the 150-mesh screen of the Tyler series.

only slightly more on further storage, mainly because of its low moisture content. The unpeeled wood kept most of its original moisture throughout the 12 months of storage and suffered a progressive increase in decay and decrease in density during this period, so that the total loss of wood substance was 14 percent of the green weight.

Loss of lignin, holocellulose, and alpha cellulose was roughly in proportion to the loss in total density.

Neither the green nor stored woods, unpeeled and peeled, showed any differences in their pulping characteristics by the sulfate process, except that a higher alkali consumption was indicated for the deteriorated than the sound wood. Sulfate pulp yields per cubic foot of wood decreased in the same proportion as did the density. The pulps from both unpeeled and peeled stored wood had lower strength properties (except for constant tensile strength) than those from the sound, green wood. Sulfate pulps sustaining greatest losses in strength were made from unpeeled wood stored for 12 months, these losses approximating 20 percent in bursting strength, 25 percent in tearing resistance, and 75 percent in folding endurance.

One of the principal effects of storage was a decrease in groundwood pulp brightness. The maximum decreases were 8 and 6 percentage points for the unpeeled and peeled wood, respectively. No important differences were noted, as between green and stored wood, in rate of grinding, energy consumption, distribution of fiber length, or pulp strength.

Discussion

Mr. X: What results may be expected from storing wood in other seasons?

Mr. McGovern: We would expect that the results would be controlled by the amount of deterioration, as measured by decay and density loss, independently of the particular season of storage.

Mr. X: How do these results compare with those recently reported by Keaton and Gillespie?

Mr. McGovern: In so far as comparisons can be made of the two investigations, it appears that there is good agreement.

Mr. X: Do the results indicate that wood can be stored under the conditions of the experiments longer than the customary 1 to 3 months?

Mr. McGovern: These experiments indicated that there is a progressive deterioration in storage, but that the allowable storage time without serious losses in yield and pulp quality, may be somewhat longer than generally believed.

Mr. X: In the work mentioned on the effect of decay of jack pine by the same organism as operating on the slash pine, what was the effect on the chemical constituents of the wood?

Mr. McGovern: As with the slash pine, the losses in the various wood constituents were roughly in proportion to the losses in density.

Mr. X: How would pitch troubles in using the groundwood pulps for paper making be affected by storage?

Mr. McGovern: Although the pulps were not made into papers, the tendency for decreases in ether solubilities in the woods with increase in storage time, might indicate a lessening of possible pitch troubles.

Deterioration of Southern Pine Pulpwood During Storage[1]

RALPH M. LINDGREN, *Sr. Pathologist, Division of Forest Pathology, U. S. Bureau of Plant Industry Soils and Agricultural Engineering*[2]

Introduction

SERIOUS deterioration of pine pulpwood during extended storage in the South has made the rapid turnover of wood supplies an essential practice. Losses have not been entirely avoidable, however, because of the need to maintain adequate wood reserves for possible emergencies, costs involved in the frequent turnover of reserve supplies, and occasional overstocking from unforeseen developments at the mill or in pulpwood production. The aggregate of losses due to these factors constitutes an important problem in a region that produced almost 10 million cords of wood in 1949.[3]

A review of literature for the southern region reveals a surprising lack of quantitative data on the damage that results from storage and the factors that affect it. This is true particularly for losses in specific gravity of wood and in yield of pulp in relation to length and season of storage. Consequently, the questions of how long pulpwood can be stored safely and what might be done to increase safe storage periods are largely unanswered.

The purpose of the present study was to determine the effect of length and season of storage on the occurrence of decay and sapstain, specific gravity and moisture content of some southern pine pulpwood. The work was done on the wood-yard of the Gaylord Container Corporation at Bogalusa, La. from July 1948 to May 1950. Rainfall and temperature conditions during this period are shown in Fig. 1. Both rough (unpeeled) and peeled pulpwood, stored at three seasons of the year (July, October and May), were sampled at different intervals during one year of storage. After sampling, the October-cut wood was shipped to the Forest Products Laboratory at Madison, Wisconsin, for further studies on the yield and quality of pulp. The results of these latter tests are presented in a separate paper.[4]

Materials and Methods

Cutting and storing of the pulpwood were carried out in late July and October 1948 and mid-May 1949. All test material was obtained from 21 to 22 year old plantations of slash (*Pinus caribaea*) or loblolly pine (*P. taeda*) near Bogalusa, La. Loblolly pine was included in the May-cut group only. The bolts were 63 inches in length, 3.2 to 9 inches in diameter and practically free of heartwood. Peeling was done by hand and usually within one day after cutting. Approximately 15 cords, half of it peeled, comprised the test material for each species and time of cutting.

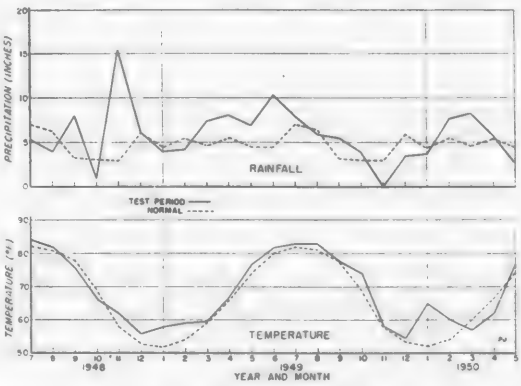


Fig. 1.—Rainfall and temperature during test period in comparison with normal values for Bogalusa, La.

Within 2 days after cutting, the pulpwood was stored in ricks about 10 feet high on the wood-yard of the Gaylord Container Corporation. Rough and peeled bolts were grouped separately but placed in the same rick. Freshly cut commercial pulpwood was stacked against the sides and back of the experimental ricks. On the whole, the conditions of storage were similar to those encountered in regular yard practice (Fig. 2).

[1] This work was done in cooperation with the Gaylord Container Corporation, Bogalusa, La. The writer wishes to acknowledge the generous assistance of this company, and the help of W. F. Gillespie, A. G. Curtis and J. Risch in facilitating the study. Appreciation also is expressed to G. M. Harvey and S. S. Sorrels of the Division of Forest Pathology for aiding in the field and laboratory work.

[2] In cooperation with the Southern Forest Experiment Station, New Orleans, La.

[3] Cruikshank, James W.—1949 Pulpwood production in the South. Forest Survey Release No. 35, 26 pp., U. S. Forest Service, September 1950.

[4] McGovern, J. N., Martin, J. S. and Hyttinen, A.—Effect of storage of slash pine pulpwood on sulphate and groundwood pulp quality. Proceedings Forest Products Research Society. 1951.

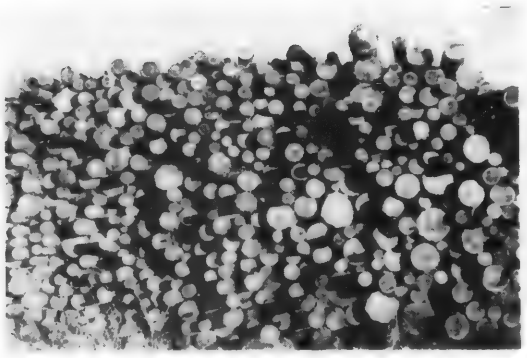


Fig. 2.—View of type of bolts and piling employed in test.

Fifty bolts were examined as a representative sample for any one test condition. These were collected from each group of freshly cut bolts, as well as at 2 to 4 month intervals from the stored wood. The 50 bolts were selected at random and for stored wood, included material from the top to the bottom of the rick. The first records taken of the stored bolts concerned their exterior appearance and condition.

In sampling the bolts, 1-in. cross-sectional disks were sawed from the middle and at points about 10 inches back from each end. Green weights of the disks were obtained immediately after sawing. From the middle disk only, the following data were taken as representative of the bolt as a whole—diameter inside bark, number of rings, and heartwood amount. From all disks, the data included specific gravity, moisture content, amount of decay and sapstain, borer and other insect presence, and the occurrence of such abnormalities as knots that might influence some of the determinations. Specific gravity was based on green volume oven-dry weight, volume being determined by the water displacement method. Oven-dry weights for moisture determinations were obtained by drying to constant weight in a forced-draft oven at about 104° C. Sapstain was recorded on the basis of the average percentage of the disk cross section that showed stain.

In recording decay, use was made of a numerical rating system, ranging from 0 to 100, termed "decay index", in which both the volume and stage of decay were considered. Essentially the same system was being tried by Scheffer in another study on jack pine pulpwood.[5] The stages or classes of decay recognized in the present study were: (1) decay discoloration without apparent softening of the wood, as determined by probing cross-sections with a knife point; (2) slight and 2.5 moderate softening of the wood; (3) fairly pronounced and 3.5 pronounced softening; (4) pronounced softening accompanied by pockets or other evidence of complete breakdown of the wood. In estimating, the entire volume occupied by decay in a disk was assigned the class that most closely typified the decay as a whole—for instance, 60 percent of class (3). In computing decay index, the percent volume of decay was multiplied by the class number and divided by 4. Thus, in a disk having 60 percent of the volume with decay mostly of the (3) class, the decay index was $\frac{60 \times 3}{4} = 45$.

An average of the data for the three disks per bolt was taken to represent the average specific gravity, moisture content, decay and stain condition for the bolt as a whole. For the entire study, 1,600 bolts and a total of 4,800 disks were involved in the determinations.

Characteristics of Freshly Cut Bolts

An analysis of the data on the freshly cut slash pine pulpwood was prompted by the wide variations in specific gravity and moisture content between bolts. Furthermore, these variations seemed to indicate certain growth relationships in the standing tree. Since all bolts were obtained from a plantation stand of definite age, the number of rings was a criterion of the position of the bolt in the tree. The results of these analyses are shown in Table 1 and Figs. 3 and 4.

The maximum range in specific gravity for all slash pine bolts was .38 to .61. Specific gravity decreased progressively from the butt toward the top of the trees (Fig. 3). This trend was even evident within the length of the individual bolts. For instance, the disks from the large end, middle, and small end of all October-cut bolts averaged .495, .492, and .487 in specific gravity. Butt bolts in the standing tree averaged about 25 percent higher in specific gravity than the top bolts.

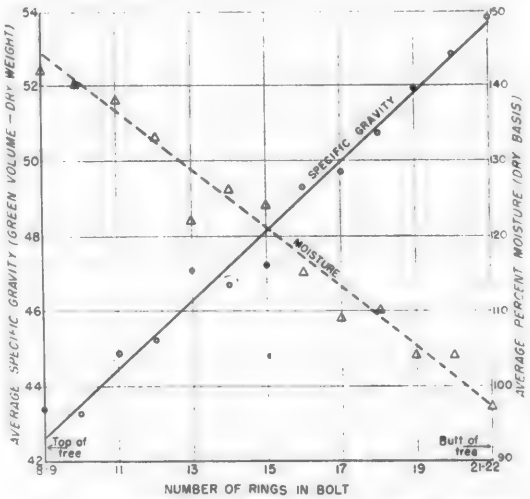


Fig. 3.—Average specific gravity and percent moisture in freshly-cut slash pine bolts from different heights in tree.

[5] Pascoe, T. A. and Scheffer, T. C.—Jack pine pulpwood deterioration in yard storage. Paper Trade Journal 131. No. 2:16–18, 20–21, 1950.

TABLE 1.—SPECIFIC GRAVITY, PERCENT MOISTURE AND OTHER CHARACTERISTICS OF THE FRESHLY-CUT SLASH PINE BOLTS OBTAINED FROM A 21–22 YEAR OLD PLANTATION STAND

No. rings per bolt	No. of bolts	Average specific gravity	Av. ring width of bolts with specific gravity— Above[1] average	Below[1] average	Average percent moisture[2]
9–10 (top)	17	.437	.180	.181	138
11	16	.449	.169	.190	138
12	23	.452	.150	.163	133
13	21	.471	.162	.161	122
14	15	.467	.144	.158	126
15	16	.472	.161	.150	124
16	16	.493	.143	.140	115
17	19	.497	.158	.131	109
18	12	.507	.151	.133	110
19	13	.519	.132	.133	104
20	11	.528	.134	.119	104
21–22 (butt)	14	.539	.161	.139	97

[1]For instance, on the first line below, the average ring width of bolts with specific gravities above 0.437 was 0.180, whereas the ring width of bolts with specific gravities below 0.437 was 0.181.
[2]Dry-wood basis.

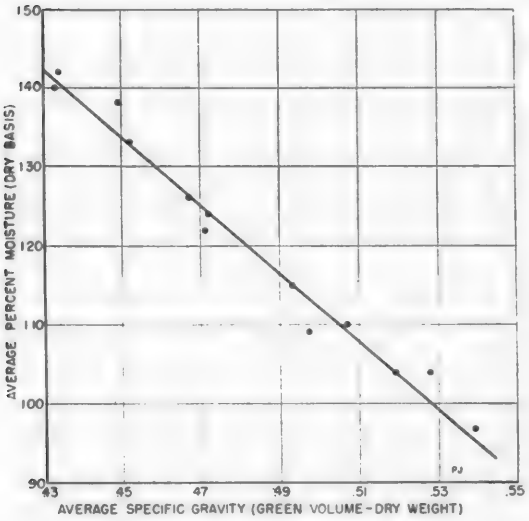


Fig. 4.—Relation between specific gravity and moisture content in freshly-cut bolts. (Points represent averages for bolt groups with different numbers of rings.

Moisture content in the bolts ranged from 70 to 175 percent of the dry weight of the wood. It increased steadily as number of rings per bolt decreased—or from the butt to the top of the trees (Fig. 3 and Table 1). The average percentage of moisture in butt bolts was only about two-thirds that of top bolts.

It follows from the foregoing trends that the relationship between specific gravity and percent moisture was an inverse one; even so, the consistency of the relationship was surprising (Fig. 4).

Bolts from the faster growing trees in this plantation stand averaged as high in specific gravity as those from the slower growing ones (Table 1). However, the number of rings per inch generally ranged from 5 to 12, so that very fast or slow rates of growth were not represented. When comparing disks within the same tree, specific gravity decreased as number of rings per inch decreased.

Deterioration of Rough (Unpeeled) Bolts

Exterior Condition

The outer bark was generally loose and easily removable after two months storage of July-cut bolts, due to heavy attack by *Ips* beetles. Similar conditions probably prevailed for May-cut bolts, which were first sampled after 6 months. In the October series, live cambium was common toward the middle of the bolts after 4 months, and could still be found after 6 months of storage. In all groups, the bark remained adhering loosely except for occasional patches, after one year. Actual loss of bark was greater for loblolly than for slash pine.

The most prevalent decay fungus on the exterior of the bolts was *Peniophora gigantea* (Fig. 5). The white to yellowish mats or crust like growths produced by it were evident, in early stages, within 2

Fig. 5.—July-cut slash pine bolts after 6 months of storage, showing varying amounts of *Peniophora* development on bark and ends, and bleaching of wood surfaces revealed on removal of bark.

and 4 months on July- and October-cut pulpwood, respectively. Within 6 months, mat development was conspicuous on most bolts, particularly on the bark and end faces toward the interior of the ricks. Knots or old branch stubs also were favored places for *Peniophora* development.

Fruiting bodies of several other decay fungi appeared on the bolts of all series. *Schizophyllum commune,* considered of minor importance, was

present usually within the first 4 months. *Polyporus abietinus,* which causes a pale sapwood rot, was fairly common after 4 to 6 months. A destructive brown-rot fungus, *Lenzites saepiaria,* appeared after 6 months and increased in prevalence thereafter, particularly on May-cut loblolly bolts which also were the driest ones in late stages of storage. Occasional fruiting bodies of two other organisms remained unidentified.

Removal of the bark showed moderate to pronounced bleaching of wood surfaces under practically all mats of *Peniophora,* indicating decay in the wood below (Fig. 5). A light to fairly dense white growth of the fungus usually covered the bleached areas. Bleaching also was common toward bolt ends exposed to the outside of the ricks, and in bolts comprising the top layer in ricks, even when *Peniophora* was not seen on the bark. It was most prevalent toward the ends during early storage, and was later associated often with old branch stubs or knots in mid-parts of the bolts. In the absence of bleaching, the wood surfaces were dark brown in color, or stained bluish-black by sapstaining fungi.

In addition to *Ips* bark beetles, ambrosia beetles and wood borers (*Monochamus* spp.) showed varying degrees of attack of all pulpwood series. Ambrosia attack occurred early but was never heavy, and was most common in the larger bolts. Borers were first noticed after 6 months of storage of the July and May-cut groups, particularly in young wood of low specfic gravity. With the possible exception of the May-cut series, the amount of wood lost due to tunneling by insects appeared to be relatively minor.

Exterior evidences of important deterioration of the wood usually were present. Significant decay during the first 6 to 9 months of storage was invariably indicated by *Peniophora* mats on the bark and ends, and/or bleaching of wood surfaces. Later decay caused by the more destructive, but localized, brown rot fungi often was revealed by fruiting bodies or badly disintegrated spots at or near the surface. In the absence of such criteria, the bolts were seldom in a badly deteriorated condition.

Decay and Sapstain

The average amount of decay, as measured by the "decay index", and the average percent of sapstain for the different lengths and seasons of storage are shown in Table 2. Since some inconsistencies developed in the application of the decay rating system, the estimated losses in specific gravity should also be considered in making decay comparisons.

Decay development for the first 6 months of storage was more rapid in the May- and July- than in the October-cut bolts, and in loblolly as compared to slash pine. During the 6 to 9 month storage period, however, decay in the October series increased greatly. After 12 months, loblolly still showed more decay than slash pine, but the differences between species and season of storage were small in comparison to those after 6 months. Although decay varied greatly between different bolts, there were very few bolts in any series with only minor decay after 6 months.

Early decay in all series was concentrated largely in the ends of the bolts. Even after 6 months, about one-half of the October series showed little or no decay in the mid-parts of bolts. The rate of decay also varied between the ends exposed to the outside versus the inside of the ricks. Thus, the rate was most rapid in the outside end of the October-stored bolts but in the inside end of the May and July series. Although such differences within bolts tended to be obliterated with longer storage periods, they

TABLE 2.—UNPEELED BOLTS—PRELIMINARY DATA ON PINE PULPWOOD CUT IN JULY AND OCTOBER, 1948 AND MAY, 1949 AND STORED FOR DIFFERENT LENGTHS OF TIME. EACH FIGURE REPRESENTS THE AVERAGE OF 50 BOLTS

Time of cutting and months in storage	Bolt diam. inches	Rings per bolt number	Moisture content (dry basis) percent	Spec. gravity (Green Vol.—oven-dry wt.)	Loss in spec. gravity (estimated)[1] percent	Sapstain[2] percent	Decay index
July-cut (1948)—slash							
0	4.8	14.4	120	.485	0	0	0
2	4.6	14.1	117	.456	3–5	11	7
4	4.6	14.7	108	.449	6–8	7+	24
6	4.6	14.2	104	.443	7–9	6+	28
9	4.4	13.8	119	.432	9–11	8+	34
12	4.5	15.2	90	.431	11–13	14+	42
October-cut (1948)—slash							
0	4.5	15.3	113	.491	0	0	0
4	4.4	15.3	109	.480	1–3	3	12
6	4.3	15.0	103	.465	4–6	2+	22
9	4.4	15.6	90	.444	9–11	8+	46
12	4.5	15.2	85	.417	13–15	18+	55
May-cut (1949)—slash							
0	4.5	15.0	121	.477	0	0	0
6	4.5	15.6	75	.451	7–9	21+	28
9	4.5	15.9	62	.443	9–11	17+	50
12	4.6	15.6	46	.422	13–15	14+	64
May-cut (1949)—loblolly							
0	5.3	15.1	122	.475	0	0	0
6	5.0	15.5	75	.446	8–10	28+	42
9	4.8	15.0	54	.431	10–12	20+	52
12	4.8	14.9	36	.417	13–15	16+	67

[1]See text.
[2]Later obliteration of sapstain by decay is indicated by +.

TABLE 3.—DIFFERENCES IN MOISTURE CONTENT, SPECIFIC GRAVITY, STAIN AND DECAY IN DIFFERENT PARTS OF THE BOLTS AFTER 6 MONTHS OR 1 YEAR OF STORAGE. EACH FIGURE REPRESENTS AVERAGES FOR 50 BOLTS

Time of cutting and months in storage	Moisture content			Specific gravity			Stain			Decay index		
	Out.[1] end Pct.	Mid.[1] part Pct.	Ins.[1] end Pct.	Out. end	Mid. part	Ins. end	Out. end Pct.	Mid. part Pct.	Ins. end Pct.	Out. end	Mid. part	Ins. end
Unpeeled												
July-cut slash pine												
6	105	109	97	.446	.450	.435	8	4	7	22	23	38
12	91	[illegible]	88	.425	.443	.429	15	14	13	46	35	47
October-cut slash pine												
6	94	118	97	.456	.472	.466	4	1	3	37	[illegible]	25
12	85	90	82	.399	.435	.416	35	7	14	64	44	56
May-cut slash pine												
6	71	77	77	.454	.453	.445	31	15	16	27	25	34
12	41	52	45	.420	.427	.421	14	13	15	65	60	66
May-cut loblolly pine												
6	70	79	76	.447	.449	.444	32	24	27	41	40	44
12	34	[illegible]	35	.422	.418	.411	19	14	17	67	67	69
Peeled												
July-cut slash pine												
6	33	33	33	.453	.453	.450	31	27	31	21	23	25
12	24	29	30	.44[illegible]	.439	.434	36	34	37	31	42	48
October-cut slash pine												
6	30	31	30	.466	.470	.469	16	16	17	33	31	30
12	22	23	23	.460	.461	.457	13	18	21	33	32	36
May-cut loblolly pine												
6	24	24	25	.459	.460	.457	48	43	41	21	21	26
12	22	23	21	.464	.463	.463	42	41	[illegible]	31	29	29

[1]Outside end—Data taken 10 inches back from the bolt ends that were exposed to the outside of the rick.
Middle part—Data taken from the middle of the bolts.
Inside end—Data taken 10 inches back from the bolt ends that were toward inside of the ricks.

were still evident after 6 months and usually after 1 year (Table 3).

A comparison of the amount of decay in relation to diameter of bolt was made by dividing the bolts into the two classes of 4.5 inches– and 4.6 inches+. The data for the 6 month storage period are shown in Table 4. Although the spread in diameters was small, the bolts of large diameter tended to show a

TABLE 4.—DIAMETER OF BOLTS IN RELATION TO MOISTURE CONTENT, SPECIFIC GRAVITY, DECAY AND SAPSTAIN. THE BOLTS IN EACH STORAGE GROUP WERE DIVIDED INTO THE TWO CLASSES OF 4.5– AND 4.6+

Time of cutting and months in storage	No. of bolts	Diam. inches	Rings per bolt No.	Moisture content percent	Specific gravity	Stain percent	Decay index
Unpeeled							
July-cut (slash)							
0	20	3.8	12.2	131	.464	0	0
6	22	3.8	11.9	107	.417	6	30
0	30	5.6	15.9	114	.500	0	[illegible]
6	28	5.2	16.1	101	.464	[illegible]	26
October-cut (slash)							
0	27	3.8	14.0	119	.479	0	0
6	29	3.4	12.9	106	.449	[illegible]	24
0	23	5.4	16.8	104	.510	0	0
6	21	5.4	18.0	[illegible]	.489	2	21
May-cut (slash)							
0	25	3.7	11.5	133	.448	[illegible]	0
6	24	3.5	12.9	71	.428	23	35
0	25	5.4	18.6	109	.504	0	0
6	26	5.5	18.1	78	.472	19	23
May-cut (loblolly)							
0	18	3.6	12.3	127	.464	0	0
6	21	3.8	14.2	62	.447	24	52
0	30	6.2	17.0	119	.481	0	[illegible]
6	29	5.8	16.5	84	.446	31	34
Peeled							
July-cut (slash)							
0	20	3.8	12.2	131	.464	0	0
6	30	3.8	12.8	32	.442	36	18
0	30	5.6	15.9	114	.500	[illegible]	0
6	19	5.3	16.2	35	.462	22	33
October-cut (slash)							
0	27	3.8	14.0	118	.479	0	0
6	27	3.7	12.8	29	.463	19	28
0	23	5.4	16.8	104	.510	0	0
6	22	5.4	17.6	32	.475	13	[illegible]
May-cut (loblolly)							
0	18	3.6	12.3	127	.464	[illegible]	[illegible]
6	16	3.7	12.8	22	.459	49	14
0	30	6.2	17.0	119	.481	[illegible]	0
6	33	5.9	15.3	[illegible]	.461	41	27

lower decay index in all series. Some of the differences were of questionable significance but a similar trend was evident for all storage periods.

Peniophora gigantea was responsible for practically all of the decay during the first 6 months of storage. Its inward progression from the surfaces often continued until general decay had been produced. This was accompanied by a straw to white-colored bleaching of the wood surfaces. Early stages of decay showed a slight to moderate softening of springwood only. Later stages were characterized by a pronounced softening of the springwood and some attack of the summerwood, without the formation of pockets or cracks in the wood. After 6 months, a brown rot, caused by *Lenzites saepiaria,* and one or more orange to brown rots of unknown origin increased in prevalence. These produced localized pockets or areas of badly disintegrated wood, often near the surfaces of the bolts (Fig. 6). After 1

Fig. 6.—Interior condition of some May-cut peeled (8 bolts on left) and rough slash pine bolts after 1 year of storage. Note prevalence of stain in the peeled bolts, also the destructive brown rot, particularly in the rough bolts of small diameter.

year, the brown rots were found in varying amounts in most of the May-cut bolts and in 20 to 40 percent of the July and October series.

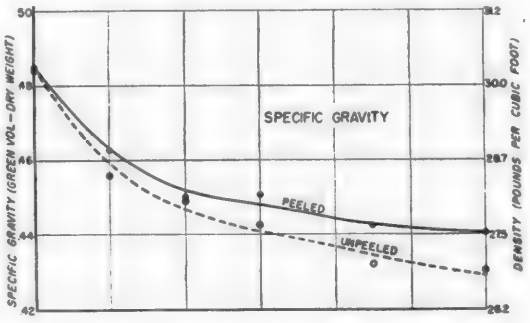
Sapstain. Stain occurred as patches, streaks or pie-shaped areas that varied in color from greenish-blue to black. It developed most rapidly in the ends of the bolts and often did not extend far below the surfaces in the mid-parts, except after extended storage. The measurement of stain was greatly complicated by the bleaching or obliterating effect of decay as storage periods increased. The result was that little relation between amount of stain and length of storage was evident. Therefore, the percentages that were recorded after decay became common have little individual significance.

In general, sapstain was more prevalent in the May- than in the July- and October-cut bolts, and in loblolly as compared to slash pine (Table 2). The highest average percentages recorded were 28 for loblolly and 21 for slash pine, both May-cut groups stored 6 months. Development of stain apparently had been rapid in the May and July series, but very slow in the October one. The more rapid staining of end- as compared to mid-parts of the bolts was evident usually for 6 months or more (Table 3). Differences between the ends were not consistent, but more stain usually was recorded for the outside end.

Except for entrance through ends or bruised places on the sides, the development of stain was associated almost always with insect attack. However, insect attack alone could not account entirely for the differences in staining of ends versus mid-parts of bolts, or the slow staining of the October series.

Specific Gravity and Moisture Content

The average specific gravity and percent moisture for the different storage groups are presented in Table 2. The same data appear graphically for each of the seasons of storage in Figs. 7, 8 and 9.



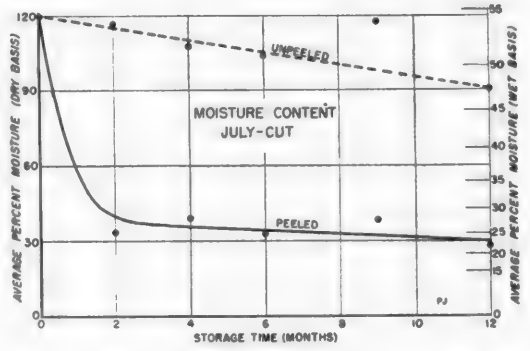


Fig. 7.—Average specific gravity and percent moisture for July-cut bolts after different lengths of storage.

Average specific gravity of the wood for the different groups decreased as length of storage increased. Although these data indicated that losses in specific gravity had occurred, their significance in terms of actual loss required that the initial specific gravities for each bolt group be determined. In approximating initial specific gravity as closely as possible, use was made of the relationship shown between average number of rings per bolt and specific gravity in the three freshly cut groups that were analyzed at the start of storage (Fig. 3). The percent losses in specific gravity that were obtained,

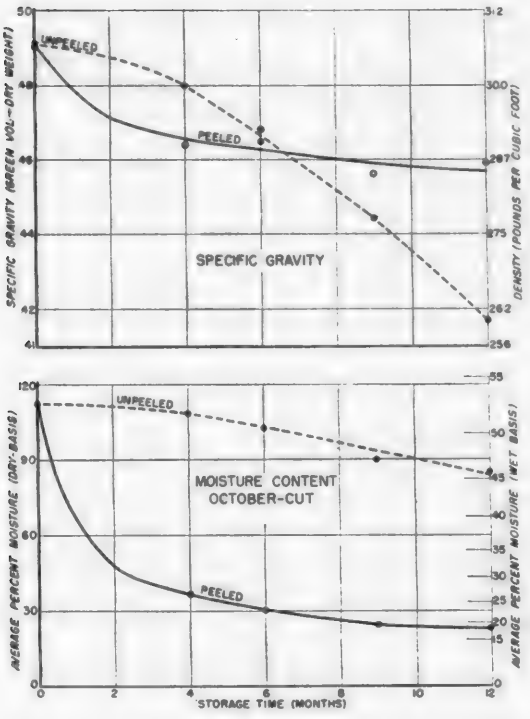


Fig. 8.—Average specific gravity and percent moisture for October-cut bolts after different lengths of storage.

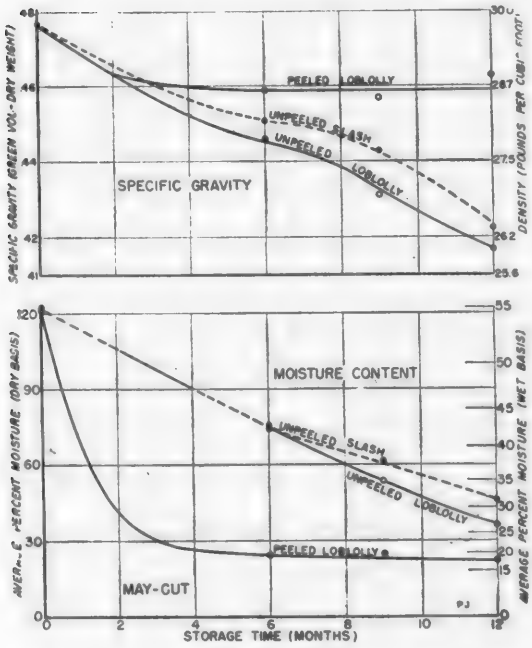


Fig. 9.—Average specific gravity and percent moisture for May-cut bolts after different lengths of storage.

based on initial specific gravities adjusted for average number of rings per bolt and with some allowance for variations, are presented as a range in Table 2. The average of the range for each storage group was used in preparing Fig. 10.

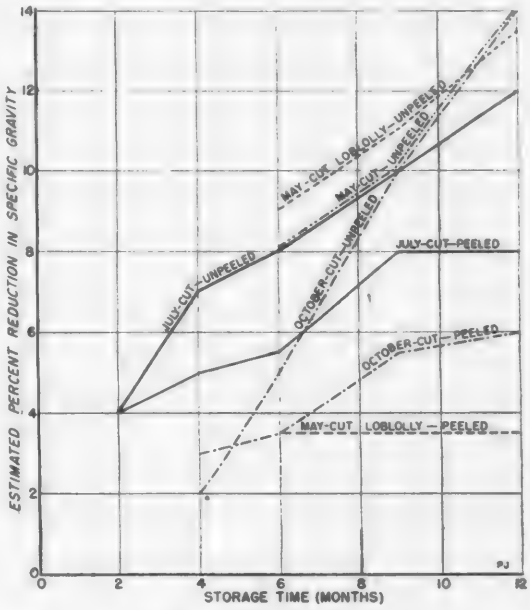


Fig. 10.—Estimated percent reduction in specific gravity of all test groups after different lengths of storage.

Considering slash pine only, losses in specific gravity for the May- and July-cut bolts were closely similar. They were greatest during the first 6 months of storage, at which time both groups had been reduced 7 to 9 percent. In contrast, losses were low in the October series during the first 6 months but increased rapidly thereafter. After 9 and 12 months, reductions in specific gravity ranged from 10 to 15 percent, regardless of when storage started.

Loblolly showed slightly greater losses in specific gravity than slash pine during the first 9 months of storage. After 1 year, the estimated reduction for the two species was about the same (Fig. 10).

Specific gravity losses usually were greater in the ends than in the mid-parts of bolts (Table 3). Reductions of 25 percent or more in the end region after 9 to 12 months of storage were not infrequent. Although losses were appreciably higher in outside than in inside ends of the October groups, the reverse condition usually prevailed in the May and July series.

Moisture content. The moisture content of slash pine bolts continued favorable for decay development even after 12 months of storage. Drying was particularly slow in the July and October series, which still averaged 85–90 percent in moisture after

12 months of storage (Table 2 and Figs. 7, 8 and 9). In comparison, water loss from the May-cut bolts was much more rapid; average percentages of moisture were 75 and 46 for the 6 and 12 month groups, respectively.

Loblolly differed little from slash pine for the first 6 months, but showed faster drying rates thereafter. The low average moisture content of 36 percent after 12 months indicated that conditions of general decay retardation were being approached.

Moisture contents were consistently lower toward the ends than the mid-parts of the bolts (Table 3). Differences often were small, but in some cases were as much as 20 percent. As between ends, the outside end usually was lowest in average moisture percent in the October and May groups but highest in the July-stored series.

Losses in moisture were appreciably greater in bolts of small as compared to large diameters (Table 4). The faster drying of the small bolts was most evident in the May-stored groups.

Deterioration of Peeled Bolts

Exterior Condition

The most pronounced changes in the exterior appearance of all bolt groups occurred within the first few months of storage. Staining of the surfaces usually was rapid and was accompanied by varying amounts of green mold (*Trichoderma*). Although such discolorations were fairly general, they often were heaviest toward the middle and inside ends of the bolts. Insect attack was absent except for slight scouring by *Ips* under occasional bark patches, and minor Ambrosia boring in some of the larger bolts.

As in rough bolts, *Peniophora gigantea* was the most common decay fungus. Light mats or mycelial patches produced by it were scattered over the surfaces within 1 to 3 months in all storage groups. They were least prevalent in the May-cut series. The mats formed a thin crustlike covering which resembled parchment on drying, and often peeled off after 6 or more months. Wood surfaces below the mats usually were bleached but this tended to be obscured later as a result of weathering. Fruiting bodies of *Schizophyllum commune* and *Polyporus abietinus* also appeared within a few months but were never abundant. After 6 months for May- and July-, and 9 months for October-cut bolts, scattered sporophores of *Lenzites saepiaria* became evident. These increased in prevalence with longer storage, particularly in the July-cut groups, but usually were confined to less than 10 percent of the bolts.

Such exterior evidences as general *Peniophora* development and the presence of *Lenzites saepiaria* or both invariably indicated serious deterioration of the wood. Absence of these decay fungi along with bright bolt surfaces was equally indicative of sound, but not always stain-free wood. Between these two extremes, the outward criteria of interior condition were not clearly defined. Although decay fungi appeared on only a portion of the bolts, decay of varying degrees was almost universal in the wood. Large bolts with the same exterior appearance as small ones usually were the more decayed of the two. Such irregularities complicated distinctions between individual bolts but did not wholly obscure general differences between entire storage groups. However, the rather large variations in loss of specific gravity between groups were not fully foreseen from their relative outward appearance.

Decay and Sapstain

The average amounts of decay and sapstain in the different peeled groups are shown in Table 5. Although decay ratings usually were higher as losses in specific gravity increased, it is apparent that uniformity was lacking in applying the "decay index" as a measure of decay. Difficulties in determining the class of decay by probing were accentuated by having wood in varying degrees of dryness. Furthermore, visual evidences of both volume and stage of decay often were misleading because a general off-

TABLE 5.—PEELED BOLTS—PRELIMINARY DATA ON PINE PULPWOOD CUT IN JULY AND OCTOBER, 1948 AND MAY, 1949, AND STORED FOR DIFFERENT LENGTHS OF TIME. EACH FIGURE REPRESENTS THE AVERAGE OF 50 BOLTS

Time of cutting and months in storage	Bolt diam. inches	Rings per bolt number	Moisture content (dry basis) percent	Spec. grav. (green vol.—(oven-dry wt.)	Loss in spec. grav. (estimated)[1] percent	Sapstain[2] percent	Decay index
uly-cut (1948)—slash							
0	4.8	14.4	120	.485	0	0	0
4	4.4	14.6	34	.463	3–5	40	16
4	4.5	13.7	40	.450	4–6	24+	24
6	4.4	14.2	33	.451	4–7	30+	23
9	4.5	14.8	29	.442	7–9	29+	34
12	4.4	14.2	28	.440	7–9	35+	40
October-cut (1948)—slash							
0	4.5	15.3	113	.491	0	0	0
4	4.5	14.1	37	.464	2–4	17	33
6	4.5	15.0	31	.468	2–5	16+	31
9	4.5	14.9	25	.456	4–7	19+	39
12	4.6	15.6	23	.459	5–7	17+	44
May-cut (1949)—loblolly							
0	5.3	15.1	122	.475	0	0	0
6	5.2	14.2	34	.459	2–5	44+	23
9	4.6	13.8	25	.457	2–5	38+	32
12	4.7	14.6	22	.463	2–5	41+	29

[1]See text.
[2]Later obliteration of sapstain by decay is indicated by +.

color that developed during drying, and some pulling of fibers in sawing, made the wood appear worse than it was. Therefore, the general tendency was to overestimate decay in the peeled as compared to rough bolts.

The development of decay was rapid in all groups during the first 2 to 4 months of storage. Thereafter, the progress of decay was either slow or almost completely retarded. Among the groups, the July-cut slash and May-cut loblolly pine showed the greatest and least amounts of decay, respectively, after 12 months. There was little change in the condition of the May-stored loblolly pine after the initial sampling at the end of 6 months.

Differences in the distribution of decay within the bolts were not as pronounced as in the unpeeled groups. Usually, the inside end showed somewhat greater amounts than the mid-part or outside end (Table 3). Furthermore, decay in large bolts was appreciably heavier than that in small ones (Table 4).

Peniophora again was the principal cause of decay during the first few months of storage. The fungus penetrated rapidly and eventually produced its most advanced decay in the deep interior of the bolt. After 6 months of storage, spots of the brown *Lenzites* rot appeared in all groups, often near the surface and in association with checks into the wood. Only the July-cut bolts showed a great increase in the frequency of brown rot with longer storage. After 12 months, the typical pockets were found in about half of the July as against 10 percent of the May- and October-cut bolts.

Sapstain. The ranges in percent volume of wood that was stained were 24 to 40 for July, 16 to 19 for October and 38 to 44 for May-cut bolts (Table 5). Therefore, about twice as much stain was obtained in summer as compared to fall storage. For all groups, the amount of stain was considerably higher than that recorded for unpeeled bolts stored at the same time. Another difference was that the peeled bolts occasionally showed small amounts of yellow and purple stain also. These were often associated with surface mold development.

The maximum amounts of stain in all groups usually were recorded at the time of the first sampling of the bolts. Thereafter, the obliterating effect of decay acted to lower stain percentages. However, it was apparent that practically all of the staining had taken place within the first 2 or 3 months of storage and that later moisture conditions were unfavorable for stain development. Similar observations on the early occurrence of important staining have been reported for peeled pulpwood stored in the field.[6]

Distribution of stain within the bolt did not vary greatly (Table 3). Although small bolts showed more stain than large ones after 6 months of storage (Table 4), their smaller amounts of decay probably contributed to this difference.

[6] Hepting, George H.—Decay and staining of southern pine pulpwood. The Paper Industry and Paper World 17:402–404, June, 1945.

Specific Gravity and Moisture Content

Average specific gravity and percent moisture are summarized for all groups in Table 5. Comparisons with the unpeeled bolts stored at the same time are made in Figs. 7 to 10.

Losses in specific gravity for all groups showed a rapid early drop, followed by either slow or no apparent reductions with longer bolt storage (Fig. 10). Losses above 5 percent were never reached in the May-cut loblolly pine but occurred after about 4 months in the July- and 6 to 9 months in the October-stored bolts. The maximum reduction of about 8 percent was shown by the July series. Half of this loss was recorded within 2 months, after which specific gravity showed little change until storage exceeded 6 months. This later lowering of specific gravity was associated with an increase in brown rot.

Reductions in specific gravity were greater in bolts of large as compared to small diameter (Table 4). Within individual bolts, the inside end usually showed slightly higher losses than either the mid-part or outside end (Table 3).

There was a close relationship between reductions in specific gravity and average moisture contents of the wood (Figs. 7, 8 and 9). In general, losses ceased at 25 percent and were rapid only when average moisture contents for the bolt groups exceeded 35 percent.

Moisture content. Average moisture contents for all groups had dropped from about 120 to 30 to 40 percent at the time of first sampling (Table 5, Figs. 7 to 9). Moisture contents after the first sampling fluctuated within a narrow range in July, decreased slowly but steadily in the October, and remained uniformly low in the May group. At the end of the year, averages for the three groups ranged between 22 to 28 percent.

Considering all storage periods, slightly higher moisture conditions prevailed in the July than in the other series. Since fluctuations also occurred, it appeared that pick-up of rainwater during extended periods of wet weather had been important in the July series (Fig. 1).

The distribution of moisture within different parts of the bolts was fairly uniform after 6 and 12 months of storage (Table 3). For shorter periods, the outside end usually showed somewhat lower moisture contents than either the middle or inside end.

Differences in moisture content between small and large bolts were greatest during the first few months of storage. After 2 months for the July and 4 months for the October groups, small and large bolts showed (a) 29.2 vs. 38.9, and (b) 30.4 vs. 43.6 percent moisture, respectively. Similar differences, but of smaller magnitude, were still evident after 6 months (Table 4).

Measurement of Decay

The "decay index" used in this study proved to be a fairly accurate quantitative measure of the progress of decay and of losses in specific gravity (Fig. 11). The greatest obstacle to uniformity in its use arose in the estimation of class or stage of decay. Since such estimation is a matter of personal interpretation, the inconsistencies were kept to a minimum by having only one appraiser involved throughout the study. In applying the system, there was a uniform tendency to overestimate decay in peeled as compared to unpeeled wood (Fig. 11, A).

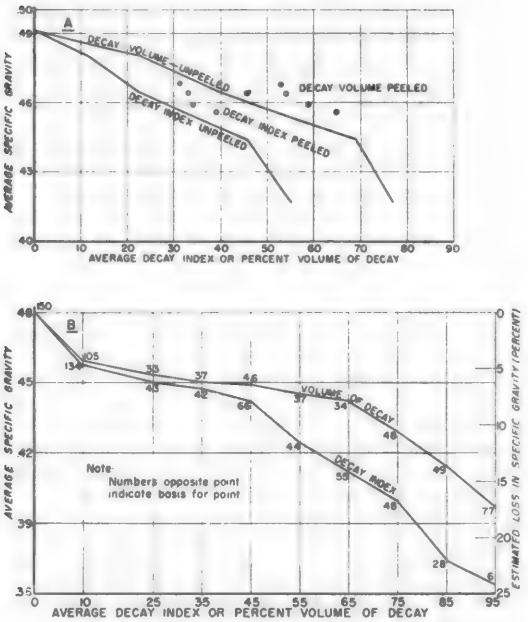


Fig. 11.—Relation between average decay index or percent volume of wood with decay and specific gravity—A, for October-cut series and B, for unpeeled bolts having 14 to 16 rings, from all test groups.

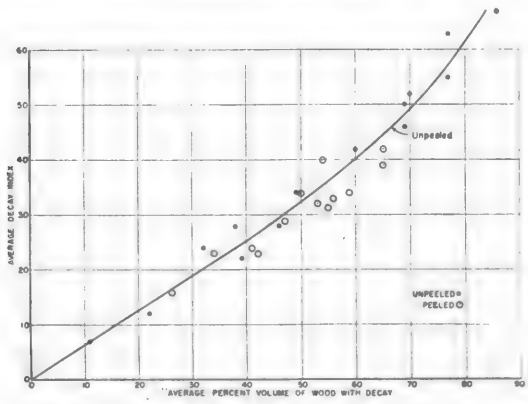


Fig. 12.—Relation between percent volume of wood with decay and the decay index among the different test groups. (Each point is average for 150 disks.)

A comparison of the "decay index" with the volume of wood that was decayed showed that the two were closely related (Fig. 12). This was reported also from a study on jack pine in which *Peniophora* likewise was the most important decay organism (5). Apparently, with decay caused largely by one fungus, the simple estimate of percent volume of wood with decay, provided it does not exceed the 80 to 90 percent point, is as satisfactory as the "decay index" for measuring decay progress and estimating corresponding losses in specific gravity. The present data for unpeeled bolts of about the same initial specific gravity, based on number of rings, gave specific gravity losses of 4 to 6, 6 to 8, and 10 to 12 percent when 25, 50 and 75 percent, respectively, of the volume of wood showed decay (Fig. 11, B). Such relationships would not be applicable to other cases of deterioration in which different fungi and species of wood were involved.

Weather and Deterioration

The period of July 1948 to May 1950 usually was much above normal in both temperature and rainfall (Fig. 1). The outstanding features in relation to pulpwood deterioration were the two warm winters in which monthly averages were never below 55°, and the long spell of high rainfall during the spring and summer of 1949. Both the July 1948 to July 1949 and October 1948 to October 1949 series were characterized by almost continuously warm and wet weather, with abnormally high rainfall extending for 5 months or more at the close of the periods. The year of May 1949 to May 1950 also was above normal in temperature, particularly during the winter, but had rather long periods of both above and below normal rainfall.

Effects on Unpeeled Bolts. In the deterioration of the unpeeled bolts, rainfall was secondary to temperature as an influencing element of weather. Only the May-cut loblolly bolts had approached the critical zone of 30 percent or below at the completion of the tests. By this time, the bolts already had been carried beyond any reasonable period of storage, based on the heavy deterioration that had occurred. Therefore, the abnormally high rainfall during much of the period probably introduced only minor differences in results between the storage groups, or between the test periods and more normal years.

The high temperatures during most of the study were of minor or great importance, depending on the time of their occurrence. Those between early May to late September probably had little effect on a rate of decay that always is rapid at this time in the South. On the other hand, the abnormally high winter temperatures undoubtedly increased deterioration at a time when decay always is retarded (but seldom stopped) in this region. Since both winters were warm, it is unlikely that the one-year comparisons between the July, October, and May series were affected greatly. However, more normal winter tem-

peratures probably would have led to somewhat less deterioration during fall and winter storage. This would have resulted in larger differences between groups for storage periods under one year and also, to less total deterioration for all groups for 9 to 12 months of storage.

Effects on Peeled Bolts. Moisture was the critical factor in the deterioration of the peeled bolts. Within 2 to 4 months, drying had reduced moisture contents to a point that was retarding decay development. Under these circumstances, the abnormally high rainfall during much of the test period undoubtedly tended to increase deterioration. The high temperatures, on the other hand, might have had their greatest effect in decreasing decay, due to acceleration of rate of drying.

Abnormal rainfall was most prolonged in the July- and October-cut groups. These groups maintained higher moisture contents throughout the storage period, and eventually showed greater decay and losses in specific gravity, than the May-cut series. An increase in decay in both groups, after 6 months of storage, and fluctuations in the moisture content of the July series, were associated with the longest spell of wet weather during the test period. There was some evidence that decay was encouraged more by prolonged than by frequent short periods of wet weather. Although less deterioration for July- and October-stored groups might have been shown during years of more normal rainfall, the uncertain effect of temperatures that also were high complicates such comparisons.

Discussion and Significance

The much higher specific gravity and lower moisture percentages for freshly cut butt as compared to top bolts in the stand that was sampled are highly significant in relation to pulp yields. Appreciably more pulp would have been obtained from the butt than from the top bolts, whether the bolts were measured by volume or weight. On a volume basis (cord), their yield would have been more because of higher specific gravity; on a weight basis, greater yields would have resulted from the much lower moisture percentages.

The effect of season of year of storing on subsequent deterioration was less pronounced for peeled than for rough wood. In peeled wood, moisture during much of the storage period apparently was the most important limiting factor in decay development. Therefore, even though the fall-cut group deteriorated slowest for the first 5–6 months, it eventually showed greater decay than the spring-stored or driest series. For unpeeled wood, much less deterioration occurred during the first 6 months of storage of fall as compared to summer-cut wood. After 9 and 12 months of storage, losses were very similar in all groups. During years of more normal winter temperatures, the differences between groups for 9 months of storage probably would have been greater. However, it seems unlikely that important effects of season of cutting extend beyond the 9 to 12 month storage period for unpeeled bolts.

The general belief that peeling is highly effective in reducing deterioration apparently requires some qualification in the Gulf States. Peeled bolts in these tests were more heavily stained than rough ones, regardless of season of cutting or length of storage. Furthermore, peeled wood showed the most rapid decay and losses in specific gravity for the first 2 months of summer and 4 to 5 months of fall and winter storage. For periods no longer than this, leaving the bark intact would seem preferable to removing it. For longer storage, however, a progressive advantage in reducing losses would be expected from peeling.

Since the size and type of pulpwood to store often could be regulated, the possibilities of reducing deterioration in this way warrant consideration. Considering rough bolts, there was evidence in these tests that decay was slower in large than in small bolts, and in mid-parts as compared to the ends. Therefore, it appears that storing as large and as long pulpwood as possible would reduce losses in practice. Large bolts also would tend to average higher in specific gravity than small wood so that less volume, and yard space, would be needed for storage. Thus, 25 percent less volume of the butt than of the top bolts in this study probably would have represented similar reserve supplies in terms of pulp. As to peeled wood, small bolts showed appreciably less decay than large ones so that storing small or split bolts would have definite advantages from a deterioration standpoint.

The high moisture contents that prevailed in the rough pulpwood during storage indicated that rapid seasoning offers little promise as a means of reducing deterioration in unpeeled wood. At best, drying could be hastened only slightly, and there was reason to believe that efforts at slowing down rather than accelerating drying might be more beneficial. For instance, top bolts were at least as heavily damaged as those in the interior of the ricks. Therefore, the previously recommended practices that attempted to improve air circulation around stored rough wood must be considered of very dubious value. With peeled wood, however, seasoning was rapid and soon caused moisture to be a limiting factor in decay development. For instance, the rapid drop in moisture from about 120 to 30 to 40 percent within 4 months of storage explains why the high early losses in specific gravity did not continue. With such conditions, acceleration of drying through improved air circulation is a practical control recommendation for peeled wood.

Analyses of some of the wood that was decayed by *Peniophora gigantea* in the present study indicated that both cellulose and lignin were attacked, causing little change in the chemical composition of the wood.[4] The percent losses in pulp yields

[7] Keaton, H. L. and Gillespie, W. F.—Effect of storage of southern pine on pul yield and quality. Paper Mill News 73: No. 45:14. 1950.

from the decayed wood seemed to be represented largely by the percent reductions in specific gravity of the stored wood. This would not be true of the later decay caused by *Lenzites saepiaria,* which, however, was relatively unimportant except after prolonged storage. Since this fungus is a destroyer of cellulose primarily, its effect on pulp yields would greatly exceed that indicated by the losses in specific gravity. In this connection, it is interesting to note that *Peniophora gigantea* apparently is a predominant decay fungus on pine pulpwood in the Lake States (*5*), as well as in the South and Southeast. In practice, there are such additional losses from decayed wood as those caused in screening and by breakage in the barking drum. These probably assume increasing importance as deterioration becomes greater with longer storage periods.

Losses in quality of pulp from stored southern pine wood have been described in a recent paper (*7*). Studies conducted along similar lines on part of the pulpwood from the present tests are reported separately.[4] Correlating results from the latter and the present studies, it appeared that pronounced changes in pulp quality and losses in yield approaching 5 percent are unlikely until after 2 months of summer or 5 to 6 months of fall and winter storage in the lower Gulf Region. During such storage, peeled wood apparently can be expected to show both yield and quality losses that are at least as high as those for rough wood.

Summary

Rough and peeled pulpwood of southern pine, stored in July and October 1948 and May 1949 at Bogalusa, La. was sampled at intervals during one year of storage.

The freshly cut pulpwood, all from a 21 to 22 year old plantation, ranged in specific gravity from .38 to .61, and in moisture from 70 to 175 percent. Butt bolts averaged 25 percent higher in specific gravity and about 40 percent lower in moisture, percent dry basis, than top bolts in the trees.

For rough bolts, specific gravity was reduced about 7 percent after 4 months of storage in late spring and summer, as compared to 2 percent for late fall and winter storage. Approximate losses after 6 months were 8, 5, and 8 to 9 percent for the July-, October-, and May-cut groups, respectively. After 9 to 12 months, losses ranged from 10 to 15 percent and were closely similar for all groups.

For peeled bolts, greatest reductions in specific gravity occurred during the first 2 to 4 months of storage and later losses were related to abnormally wet weather conditions. Approximate losses after 4 months of storage were 5 and 3 percent for July- and October-cut bolts, respectively. After 6 months, they were 6, 3, and 3 percent, and after 12 months, 8, 6, and 3 percent for the July-, October-, and May-cut groups, respectively.

The percent volume of wood with decay was a fairly accurate criterion of specific gravity losses in rough bolts. With 25, 50 and 75 percent of the wood decayed, reductions in specific gravity of 4 to 6, 6 to 8 and 10 to 12 percent, respectively, were indicated.

Specific gravity losses and the amounts of decay in rough wood were greater for small than for large bolts, toward the ends than the mid-parts of bolts and, during early storage, for loblolly than for slash pine. For peeled bolts, they were greatest in large bolts and varied only slightly in different parts of the bolts.

Moisture content of rough bolts remained favorable for decay after one year of storage. Loss of moisture was greatest in small bolts, toward the ends of bolts, and in loblolly as compared to slash pine. For peeled bolts, average moisture content dropped from about 120 to 30 to 40 percent within 4 months of storage. Losses were most rapid from the small bolts.

Sapstain developed early and was later obliterated by decay. For rough bolts, the highest percentages of stain were 28 for loblolly and 21 for slash pine, both May-cut groups. In peeled bolts, the maximum percentages were 40 for July-, 19 for October-, and 44 for May-cut bolts. Therefore, staining was most prevalent in peeled and in summer-cut bolts.

Exterior evidences of interior condition of wood were most conspicuous and consistent on rough bolts. These included fungus mats on bark and wood surfaces, bleaching of wood surfaces, and later, scattered fruiting bodies.

The most prevalent decay in all groups was caused by *Peniophora gigantea,* which attacked both cellulose and lignin. After 6 months, *Lenzites saepiaria,* a destroyer of cellulose primarily, became increasingly important. Other minor decay fungi were *Polyporus abietinus* and *Schizophyllum commune.*

Indications from the results were:

1. Losses in specific gravity (and in pulp yields[4]) of 3 to 5 percent can be expected within about 2 months of summer and 5 to 6 months of fall and winter storage in the Deep South.

2. Within the storage periods mentioned above, rough bolts are likely to show less deterioration than peeled ones. With longer storage, there will be a progressive advantage from peeling.

3. Season of storing rough wood is largely important for storage periods under 9 months. Within such periods, fall storage will reduce losses appreciably.

4. Practices that attempt to reduce deterioration by hastening drying hold no promise for rough but are important for peeled wood.

5. Practices that will reduce deterioration in rough wood include fall storage for periods up to 9 months, favoring large bolts for storage, and storing as long bolts as possible.

6. Practices that will reduce deterioration in peeled wood include those of hastening drying of bolts through improved ventilation of the ricks, favoring small bolts for storage, and splitting bolts.

Discussion

C. R. Silversides (Abitibi Power & Paper Company): Have you done any work on chemical control measures that might be useful in reducing deterioration?

Mr. Lindgren: A number of chemical spray treatments have been tried on both peeled and unpeeled pulpwood. To date, the evidence is that sprays containing 3 to 4 percent solutions of sodium fluoride or ammonium bifluoride, if applied immediately after cutting and peeling, will give a high measure of decay control in peeled pulpwood stored for as long as a year. Such sprays have been more effective than the organic mercurial or chlorinated phenol types of dips or sprays that are commonly used on lumber, posts and other products. On rough wood, sprays of the same fluoride solutions applied immediately after cutting to the ends of the bolts also leave greatly reduced decay losses for storage periods of 6 to 9 months. The latter type of treatment simply delays decay occurrence for several months, with the result that decay later becomes established and continues rapidly thereafter.

Mr. X: Is there any evidence other than that presented, that attempts at rapid drying of rough pulpwood has no promise in reducing decay losses?

Mr. Lindgren: Several other tests conducted on a smaller scale have included rough bolts stored in open crib piles as compared to bolts closely piled in ricks. Even though the open crib piling permitted far more rapid drying conditions than would be practicable for most mills, loss of moisture from the bolts still was slow, although somewhat greater than in the case of the ricked bolts. Furthermore, decay losses in the open crib piles always were at least as great as those in the ricks. In fact, the present evidence is that the greater exposure and drying in open piles probably will increase rather than decrease the decay hazard in rough bolts. This would not be true of peeled wood, however, because rapid drying of peeled bolts can be obtained and usually is a practicable method of reducing losses.

Mr. X: Since the test period was somewhat abnormal from a weather standpoint, do you think the results presented are fairly representative for more normal years?

Mr. Lindgren: I believe the data presented are fairly representative even though abnormally high temperatures prevailed during most of the two winters that were covered in these tests. Other tests run prior to and subsequent to the present ones showed specific gravity losses that were similar to those obtained in these tests, even though the weather was more normal.

Mr. X: What is your opinion of water storage of pulpwood as a means of reducing storage losses?

Mr. Lindgren: Storage under water should largely eliminate any losses due to decay for an almost indefinite period. If water storage could be done practicably, it undoubtedly would be the most certain way of avoiding losses for long periods of time. Keeping the pulpwood continuously wet by means of water sprays would seem also to be effective if it could be done properly and practicably. Such sprays have not been tried in the South and there is considerable question whether it could be carried out efficiently at most mills. However, a trial would seem worth while to determine the possible usefulness of the method.

Mr. X: I note that the fungus *Peniophora gigantea* was the most important organism throughout this work. What differences in results might be expected if other fungi than *Peniophora* were important in certain storage losses?

Mr. Lindgren: Since *Peniophora gigantea* is the type of fungus that attacks both lignin and cellulose, there is little change in the chemical composition of the wood so that losses in pulp yields are closely indicated by the losses in specific gravity of the wood. If, on the other hand, a brown-rot fungus had been concerned, *Lenzites saepiaria* for instance, the cellulose would have been largely removed, leaving mostly lignin, with the result that losses in pulp yield would have been much greater for the same reductions in specific gravity than those caused by *Peniophora.*

TECHNICAL SESSION VIII—Thu., May 10, 1951, 2:00 P. M.

General Subject: Wood Fuel

Co-Sponsor: Northeastern Wood Utilization Council

Chairman: Henry I. Baldwin—**Recorder:** Edgar L. Heermance

Harvesting Fuelwood in Stick Form

FRED C. SIMMONS, *Specialist, Logging and Primary Processing, Northeastern Forest Experiment Station, U. S. Forest Service, Upper Darby, Pennsylvania*

One of the principal reasons for the declining use of wood for fuel is the high price at which fuelwood is sold. Much of this is due to the cost of traditional harvesting methods, which may require as much as two to three man-days per cord. With modern harvesting methods and equipment this can be reduced to a fraction of a man-day per cord. The author describes new equipment, now available, and methods for harvesting and handling fuelwood more economically.

Cause of High Fuelwood Costs

THE currently higher and higher cost of fuelwood has resulted principally from higher and higher costs of labor. The production of fuelwood by old-fashioned methods requires two and even three-man days per cord. At present-day wage rates this makes wood a luxury fuel. While the production methods and facilities for handling and transporting coal and oil have been steadily improved, those for fuelwood remain pretty much as they were in Colonial days. Even logging camps in our North Woods are switching from wood to oil and coal to heat their bunk houses and cook their meals, because wood from nearby stands costs them about $25 a cord to harvest and work up into usable sizes.

This need not be so. With the aid of modern mechanical equipment and methods the man-days needed to produce a cord of fuelwood can be cut to a third or less of the number traditionally needed. The methods used by charcoal manufacturers in northwestern Pennsylvania to mechanize their wood harvesting and handling serves as an illustration. Up through the depression days of the '30's, chemical wood was cut into 52-inch lengths by hand, and the bigger sticks were split so that the largest piece would pass through a 10-inch ring. The wood was then stacked by hand along trails through the woods. These sticks were hauled out of the woods on stoneboats, usually pulled by a single horse. The sticks were picked up, one by one, loaded on the stoneboat, hauled to the roadside, and then picked up, one by one again and stacked at the side of the road. Hauling in the '30's was usually done by truck, but the sticks were again picked up singly, and loaded on the truck. The wood was hauled to the mill yard and stacked one stick at a time to season for 18 months or so by the side of tracks upon which the retort buggies ran. Finally the seasoned sticks were picked up singly, and loaded on the retort buggies, to be put into the charcoal kilns. More than three man-days of 10 hours or more were required to get a cord of wood from stump to plant. Yet the wood was being delivered for about $4 per cord.

In the '40's, particularly after the war started, labor could not be found to work at these rates, and prices went up to $10 and even $12 a cord. Still enough wood could not be obtained to meet wartime demands for charcoal. Something had to be done, and it was done. A new method of harvesting was worked out which, instead of involving handling each stick at least six times between stump and retort, eliminated this handling altogether. Splitting also was eliminated, and the period of air seasoning was cut down to about 3 months, or cut out altogether.

An Example of Cost-Cutting Operation

The reduction in handling was accomplished as follows: The trees were cut down and the limbs and tops chopped off in the woods. Then these tree lengths, in bundles of two cords or more, were hauled to the roadside behind a medium-sized crawler tractor and sulky. At the roadside the wood was cut into 12- to 15-inch lengths, instead of the traditional 52-inch sticks, by a slasher saw, consisting of a gasoline-powered circular saw that could be pulled down into each cut by hand, and a spiked roll and buggy that could advance the tree length poles mechanically for each successive cut. These short lengths fell onto a conveyor belt, which carried them up to a waiting high-side, stake-body truck or trailer, and dropped them loosely into it. Tests proved that a truck load of this loosely piled short-length wood contained as much wood volume as a load of 52-inch sticks carefully piled. At the mill yard the sticks were either dumped directly into the retort buggy, from a ramp, or onto the ground for seasoning. Because the demand was so great, many of the plants were making charcoal from green wood, in spite of the greater amount of outside heat needed and the damage to their retorts. At least one installed a successful set of predryers, which by the use of waste-stack-gases dried the wood in two days as well as it had formerly dried in the open yard in a year or more.

This solution of the chemical wood supply problem cannot be applied entirely to the problem of producing fuelwood. Fuelwood production will of

necessity probably remain a smaller scale business than even these relatively small chemical-wood operations. (The various plants use 15 to 60 cords a day.) A different product (different sizes and shapes of wood) is required.

But fuelwood production can be mechanized, and the methods of producing and handling can be streamlined. In many places attempts have been made to do this, with varying degrees of success. Because of the many variations in topography and degree of rockiness or bushiness where the wood grows; in the size and shape of the trees themselves; in types and skills of labor to be used; in distance, and routes of transportation to point of marketing or use; and in the demand of the market for kinds or sizes of wood, no one solution is possible. A big producer will be able to buy and use relatively expensive and specialized equipment. A small part-time fuelwood cutter, like a farmer, cannot afford much expenditure for equipment and for the most part would have to use what he already has available (for operation of his farm), with perhaps some inexpensive auxiliary devices.

In recent years much new equipment has become available that specifically meets the needs of fuelwood producers.

New Equipment That Helps

An important new tool is the one-man chain saw. Since World War II the power chain saw has been scaled down in size and price, and at the same time its usefulness and reliability have been increased. Good saws, capable of making cuts up to 20-inches in hardwoods, are now available in weights of about 30 pounds and costing only about $300. Properly used, test after test has proved that such saws can just about double the productivity of a man using a crosscut or bow saw, and leave him fresher and less susceptible to accidents at the end of the work day. These results cannot be attained by one man working alone. Even with the chain saw, much hand work remains, in clearing out brush, notching, limbing and measuring lengths. If the chainsaw operator has to shut off his saw to do this type of work, he is only taking partial advantage of the productivity of the tool. A second man in the crew who can do these extra jobs will leave the chainsaw operator free to keep the saw running steadily and productively.

For the really small producer the Swedish bow saw is available for making cuts 10-inches deep or less, 50 percent faster than with a two-man crosscut saw.

Tractors and Tractor Attachments

The crawler tractor is the second new tool to make the task of fuel harvesting easier and more productive. Good Diesel-powered tractors in sizes as small as 30-drawbar horsepower have been available for some time, but these are pretty big and expensive for the average fuelwood producer. Recently several good gasoline-powered crawler tractors below 20-horsepower and even down to 8-horsepower have come on the market. Along with these there have been developed and manufactured several accessory devices such as rear-mounted winches, sulkies, hydraulic-lift drawbars, and even dozer blades to make these little tractors really useful woods tools. With them the fuelwood producer will find that he can emulate the example of the chemical wood producers and bring tree lengths of second-growth hardwoods out of the woods, where they can be bucked up more easily and accurately at the roadside.

With the exception of level, open woodlands on the Coastal Plain wheel tractors are not much good in the woods. They do not have enough traction, and their center of gravity is so high that they are dangerous to operate. Recently, however, an inexpensive conversion kit has been marketed to supply crawler tracks for two of the most popular and adaptable makes of wheel tractors.

No tractor is much good in the woods without a rear-mounted winch. With such a winch the operator can reach into bushy or rocky places, or down slopes and bring in sticks of timber with less power, and less danger to himself and his machine than if he is working with the bare drawbar. If he hits a muddy place or an upgrade on his trip to the landing he can drop his load, go ahead with the tractor alone, and then winch the load up to the machine, getting 50 to 80 percent more power than was available at the drawbar. At least three manufacturers are now marketing excellent winches for rear mounting on small crawler and wheel tractors.

Bucking Rigs

There are several easy and efficient ways of bucking up tree-length sticks at the landing. One, adapted to use with the same one-man power saw as is used in felling and bucking in the woods, is the bucking ladder.

The bucking ladder (Fig. 1) is merely an arrangement of poles and crossbars upon which the

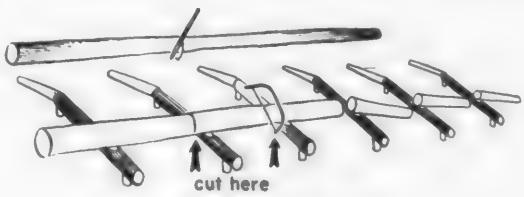


Fig. 1.—Bucking ladder.

tree-length stick is rolled, to get it up off the ground for bucking. It may be two parallel poles, with cross bars spiked on top of them at the intervals where cuts are to be made (2 feet or 4 feet apart) arranged so that it can be skidded from place to place along the roadside. Or it can be a semi-permanently located structure built out from the hill-

side like a skidway, with supports at the same intervals. Cuts are made just behind the supports and pinching is rarely a problem. With the ladder the cut pieces have to be picked up manually, and carried to the truck or pile.

A better rig is the bucking chute, (Fig. 2) which in its best form is a set of concave conveyor rolls

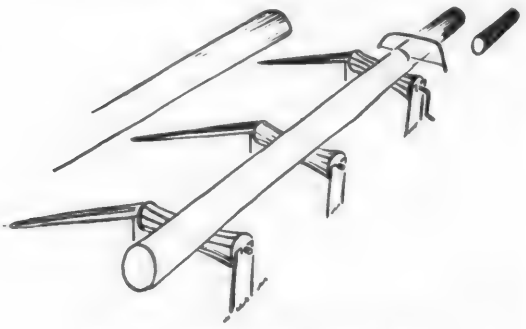


Fig. 2.—Hand operated bucking chute.

upon which the tree-length stick is rolled. With the aid of a crank, or manually, the crew pushes the stick ahead to the position where the next cut can be made, and the cut sticks all fall off in one place.

These simple rigs can be varied in all sorts of ways. A powered circular saw can be used to do the cutting. Power can also be applied to bring the pole ahead for successive cuts by means of a chain conveyor, or better yet by a spiked roll and buggy running on a short length of track. A simple arrangement using a spiked roll and trolley line, and a circular cutoff saw, suitable for use by farmers and other small producers is illustrated in Fig. 3.

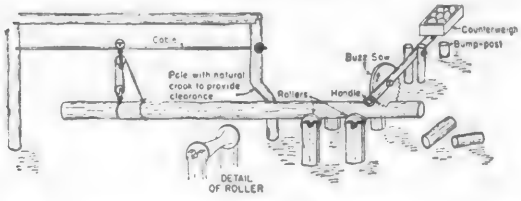


Fig. 3.—Simple bucking machine (chainsaw can be used instead of circular saw).

Splitting

Splitting is usually the toughest problem of the fuelwood producer. Many sticks will be found on almost every operation that are too big to be used for fuel unless they are split. Split wood is also desirable. It dries faster, it is easier to handle, and many users believe it ignites easier and burns better. Some kinds of wood split easily by hand, provided it is straight-grained and clear. Among these are most of the oaks and pines, cedar, poplar and basswood. Others, because of their typically interlocked grain, are very difficult to split. These include elm, blackgum, and sycamore. In any case much of the wood from which fuelwood should be made is crooked and knotty, even among the easier-splitting species. In the past, considerable quantities of wood that have been cut and yarded have been discarded because splitting was too difficult.

Several types of power splitters have been developed to reduce the labor and time spent on hand splitting. Most of them work best on relatively short lengths of wood. A vertical splitter, built by an upper New York State farmer, using a pitman arm on a flywheel, is shown in Fig. 4. It is powered by

Fig. 4.—Vertical splitter powered by electric motor.

a 3-horsepower electric motor. Horizontal splitters are also being constructed. The one in Fig. 5 is commercially manufactured tool, mounted on a sled and designed for 4-foot sticks. It uses hydraulic power from a pump on a tractor to do the splitting.

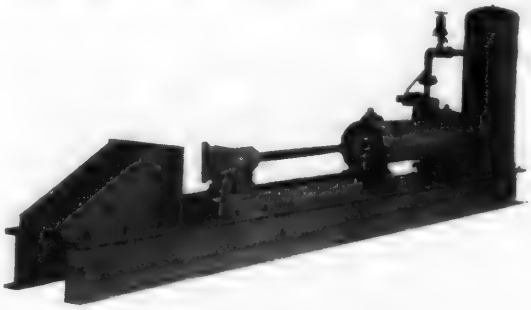


Fig. 5.—Horizontal hydraulic splitter.

There are also explosive wedges, which use black powder for splitting. The most widely-used and successful are round steel bars about 18 inches long, with a hole bored about half of their length for a powder chamber. The end at which the hole enters is tapered. These are driven into the end of the log being split, after a spoonful or two of black powder and a little dry wadding has been placed in the hole. A safety fuse is inserted in the hole at the side, and a split chunk leaned against the driven end to keep the wedge from flying too far and to increase the splitting effect. Then the fuse is lit. These explosive wedges have proved very satisfactory, even though there is little control over the way in which the bolt is split.

The most generally satisfactory splitting tool, in my opinion, is the ordinary circular rip saw. Many notheastern pulp mills are now using these, mounted in a bolting-saw table. They report that there is less loss of good pulpwood from saw kerf than there is from splintering in wedge splitting. Also the splitting is accurately controlled. Recently a small bolter mounted on wheels has appeared on the market, which is ideally adapted as a portable unit to do the splitting in the woods. With two wedge-shaped supports on the table to center and hold the round or half-round sticks in front of the saw, it would be a relatively safe and accurate tool for bolts up to 6 feet long.

Another more stationary rig for splitting even longer logs would be a V-shaped trough, with a conveyor chain mounted in either side, and a splitting saw in the center. Such a tool could be rigged up quite elaborately with a return conveyor alongside for half sections it was desired to quarter, and a power kicker in the main conveyor behind the saw and another in the return conveyor ahead of the saw to transfer the logs or sections from one to the other.

As mentioned before, split sticks dry faster than round ones. Tests have shown that drying of round sticks, with the bark on, proceeds largely from the cut ends. Eight-foot, round, unbarked sticks dry very little in a year's time in New England. Even four-foot sticks take about 18 months to dry down to about 25 percent moisture content. Two-foot sticks will lose water to this point in a good drying summer. So the shorter unsplit sticks are cut, the more rapidly they will dry.

Split sticks, on the other hand, dry from the sides as well as from the ends. Splitting, therefore, should be done before drying is attempted.

Loading and Handling Aids

Loading and transporting fuelwood requires a great deal of expensive labor if the work is done by hand. Recent developments can cut this labor expenditure materially.

Short-length wood (16 inches or 2 feet) can be loaded with a conveyor loader. Recently in northern New England there have been offered for sale two such conveyors, designed for loading four-foot pulpwood, both being highly portable, and costing less than $400 complete with motor. They can be carried by two men, and leaned against the side rack of the truck for use.

Fuelwood can also be handled in steel-strapped or cable-wrapped bundles, or on pallets. Tubular steel pallets have recently been developed for pulpwood. They can be loaded in the woods, skidded for short distances behind tractors, and loaded on the truck by means of a pair of ramps and a power winch behind the cab. At the point of delivery these pallets can be picked up and dumped by a crane, or they can be equipped on one side with quick-release safety-trip sides, that can be unlatched from the opposite side of the truck, to let the load roll and slide off onto the ground, using slope and gravity.

Steel strapping and cable wrapping make it possible to handle fuelwood more expeditiously, provided that power equipment is available for handling large-size bundles. Small bundles also present opportunities. One producer in Connecticut is bundling two-foot fireplace wood by steel strapping in units of about one-twelfth of a cord. These can be placed in the trunk of an ordinary passenger automobile and are finding a ready sale.

Bundles of a quarter cord or more can be handled by a jib boom on the truck itself, or by an independent crane. Many jib booms for truck mounting are commercially available, and some have been constructed by local mechanics. They could be used for loading the bundles at the roadside in the woods, and for unloading them at the delivery point in town.

Modern Methods Exemplified

Let us finish with two typical and specific examples of how fuelwood harvesting can be mechanized.

The first example is a farmer in northern New England or New York State who needs about 30 cords of wood to supply his new magazine-type wood-burning space heater. This stove will take sticks up to 24 inches long and 8 inches in diameter. The farmer has his own hardwood woodlot within easy tractor haul of the home place, and with guidance from the local farm forester has marked enough trees to provide the 30 cords, as well as some logs and bolts for sale, on one corner of it.

This farmer already has a Ford tractor, and for $400 he buys a conversion kit that gives it crawler tracks on the rear wheels. This gives him a much more useful tractor for general use in the mud and snow seasons. He particularly wants it for plowing out his walk and driveways and for handling barn refuse in the winter months, so this expenditure is not charged against the fuel job. A rear-mounted winch for the tractor costs him another $250.

He also buys a one-man chain saw for $300 and rigs up a power splitter by attaching a splitting wedge to an old steel shod tractor wheel. This costs him $50. The tractor pulley supplies the power. A trestle with spiked roll and crank similar to the one in Fig. 3 costs him about 6 hours of work and another $12.

His capital investment then, chargeable to the logging job is $612. With this equipment he and his boy cut up, split and stacked the 30 cords of wood, and also 1500 board feet of logs and 8 cords of white birch millwood in twenty 6-hour days. The balance sheet on this operation works out as follows:

Expenditures:		
Maintenance and depreciation of capital equipment (⅛ cost)	$204	
Supplies (gas, oil, etc.)	12	
Labor (240 hours)	240	
Total	$456	$456
Receipts:		
Sawlogs ($50 per M, roadside)	$ 75	
Turning bolts ($22 per cord)	176	
Fuelwood ($15 per cord)	450	
	$701	701
Profit		$245

The value of the fuelwood is based on the local price of coal which would otherwise have had to be purchased. This summary shows that the farmer and his boy not only got the equivalent of a dollar an hour for the time they spent on this job, but an additional $245 profit, only part of which could be charged to the value of the timber removed. In fact the operation resulted in a vastly improved woodlot where faster growth is expected on the better trees which were left.

As a second example let us take a commercial fuelwood operation, designed to produce 800 cords of fireplace wood for a nearby city market. Equipment would include a 20-horsepower crawler tractor equipped with winch and sulky costing $3,000, two one-man chain saws worth $300 each, a bolter saw for splitting, complete with motor, costing $1,000, a slasher saw with motor, worth $600, and a truck equipped with a jib boom, and a supply of ½-cord pallets costing $3,000. The entire cost of capital equipment, when new, was then $7,200, which depreciated over a 5-year period would amount to $1,240 per year.

Stumpage is purchased from nearby woodlands at $2.50 per cord. The crew consists of one power-saw operator and an axman in the woods, the tractor driver and his helper skidding the tree lengths to the landing where the other power-saw man bucks them into 6-foot lengths. The larger sticks are then split on the bolter saw, by a second man. A third man on the landing crew decks the 6-foot wood for drying. This crew of seven men decks up about 21 cords a day. When the wood is ready for sale another crew of two men breaks down the decks and cuts the wood into 2-foot lengths and loads them onto pallets. The truck driver can then lift six pallets on his truck and deliver them to customers in the nearby town. Cut-up and delivery by these three men runs at the rate of about 12 cords a day. The boss supervises the entire operation. The operation balance sheet looks about like this:

Expenditures (800 cords):	
Stumpage at $2.50	$2,000
Depreciation on equipment	1,240
Maintenance of equipment	620
Supplies, including gas and oil	500
Labor, harvesting	3,000
Labor, delivery	1,600
	$8,960

The 800 cords of wood, even at $15 a cord delivered, which is about half the average current price, would (in the city in question) be worth $12,000, thus leaving $3,040 for the boss for a half-year's work; and his equipment, with the depreciation all taken care of, available for the production of other forest products for the remaining half year.

Such examples could be multiplied indefinitely, but this should suffice to show that wood should definitely be included as one of the available fuel supplies in these critical times, and in the future.

Discussion

Charles S. Walters (Illinois Agricultural Experiment Station): The farmers in Illinois have been encouraged to burn more wood, but in our area, where coal is readily available, the interest in cutting fuelwood is low. Many landowners view this as an arduous, low-paying, low-profit job. While about half of those I've talked with are satisfied with the return for their labor; half of them claim a loss on their work perhaps making only 60 cents an hour. In land clearing, of course, part of the cost can be recovered by cutting fuelwood.

Edgar L. Heermance (Northeastern Wood Utilization Council): Would not mechanized equipment and improved harvesting methods encourage production?

Mr. Walters: Yes, that's true. I believe that ability and equipment are the main factors influencing the farmers' interest. Men handy with woods tools are not discouraged by the hard work. Custom cutting would appeal to our farmers because they are familiar with custom services for harvesting other agricultural crops. Mechanical equipment, such as power saws, does make the job easier and encourages production.

Fred E. Winch (Cornell University): There is still a great interest in wood as a fuel. In New York State, we put out some publicity on the new wood distillation furnace, and received over 3,000 requests for further information. Many units have been purchased.

B. C. Williams (U. S. Navy Department): In our shipyard, we have a large amount of sawdust to dispose of, but nobody seems to want it. The portable mills let piles of sawdust accumulate. As to cutting fuelwood, the farmer today is different from the farmer of yesterday. He wants his day off and is not interested in extra-curricular activities. The smaller the acreage, the worse it is; the man even objects to holding a light while the old lady cuts up wood.

Richard A. Hale (R. A. Hale Logging and Lumber Co.): My observations of the improved wood distillation stoves are that they do well when properly handled. The great difficulty is to get people to learn how to run them. They are inclined to operate them like the ordinary up-draft stove. There should be a steady rather than an intermittent fire, and a temperature high enough in the combustion zone to avoid creosote trouble.

Henry W. Hicock (Connecticut Agricultural Experiment Station): After years of research, my general conclusion is that there are certain inherent difficulties in the burning of stick wood. In order to get good combustion, it is necessary to provide for mixing the correct amount of air with the gases produced. When appreciable quantities of stick wood are involved, supplying and mixing the correct amount of air with the gases is quite difficult. The newer types of slow combustion stoves are a definite improvement over the conventional wood burning equipment used in this country, but there still are factors which cannot be overcome without greatly complicating the apparatus. I believe the answer lies in some sort of stoker device which will feed relatively small quantities of wood into a combustion zone, where it will be mixed with the right amount of air and burned at a fairly high rate.

Mr. Swain: What about fuelwood in cube form?

Mr. Simmons: We have been cooperating on that with the TVA. The idea is to cut sticks into 2-inch disks, which are then split, supplying a fuel in chunk form that can be fed to a furnace with a mechanical stoker. The only difference from coal would be that the bulk of the fuel is about doubled. Ted Fabyan of Portland, Oregon, has developed a gang saw that will make 14 disks. In the test plant of the Forest Service at Beltsville, Md., they are cutting wood with a one-man chain saw, hauling it in with a crawler tractor, splitting with a rip saw, piling on skids for seasoning, and then cutting into 2-inch lengths, which can be handled mechanically.

Mr. Heermance: What would disk wood cost?

Mr. Simmons: The production of such fuel should cost less than a man-day per cord, which makes it comparable with the production of coal or oil.

Mr. Hale: What percentage of loss would there be in the disking process?

Mr. Simmons: What you lose, of course, is the sawdust. In a gang saw with a $\frac{1}{8}$ inch kerf, you would lose about 7 percent of the original wood.

Source and Availability of Chipped Wood For Fuel

R. R. ALEXANDER, *Logging Engineer, Carthage Machine Company, Carthage, New York*

This paper summarizes generally the quantity of logging and sawmill waste available in this country as a potential source of chipped-wood fuel.

Introduction

THE purpose of this paper is to present material for discussion in broad outline and to attempt to show something of the source and economics of the production of chipped wood rather than to cite specific evidences of its utilization for fuel. There is a tremendous volume of wood called waste, from logging, lumbering, pulping and other wood working industries, readily useable as a raw material for our purpose. This is aside from the residues accruing from the processing of primary growth. Since pulping processes in the main cannot tolerate bark, the fuel chip producer does not have to compete with them for raw material, so this discussion will be limited to the processing of such waste reduction as logging slash, sawmill waste, forest improvement cuttings, culls and species considered to be weed trees.

We have been asked to consider how chipped wood fuel can serve in the mobilization in this emergency. In two conflicts we have had to ration petroleum products drastically, and an all-out war could play havoc with our supplies. We have not suffered aerial attack on this continent, but are well aware what this could do to our long-range transport. Both petroleum and coal are dependent on long-range transport for distribution to the vast majority; wood is relatively locally available. Recent strikes in coal fields and transportation industries give us ample evidence of what could be the outcome of sabotage or bombing. The use of wood fuel could release valuable long-range facilities, but we must show that the use of chipper wood for fuel is not only economically possible in war, but desirable in peace, if any real service is to be given by the forest products industry.

Any suggestion that we return to chunk-wood fired and manually-controlled furnaces and heaters would receive and merit a poor reception. Our modern economy, at the domestic level, revolves around the automatically fed and thermostatically controlled unit. Chipped wood burners can and do meet these requirements.

Types of Fragmented-Wood Fuel

What is chipped wood? In the petroleum and coal industries we may select processed fuel suitable to our specifications, such as fuel, furnace, diesel and kerosene, in oil; egg, stove, nut, pea and stoker in coal. Perhaps the only two grades of fragmented wood extensively used for fuel are sawdust and hogged fuel. Lately these two grades have been augmented by a processed wood loosely termed "chipped fuel". It would seem that, if wood fuel is to be competitive, a breakdown in grades similar to those for petroleum and coal is necessary. The stoker and furnace manufacturers have done well to devise equipment to use our crudely processed material, but it seems that the wood fragmentation groups have not kept pace and so wood, man's oldest source of heat, has fallen into disrepute as a fuel.

Since sawdust in bulk has been used successfully for years on the Pacific Coast and elsewhere, it is not proposed to discuss it other than to remark that its uniformity suits it to automatic feeding and thermostatic control and to note that there are two grades, coarse and fine, the first named considered most desirable. But sawdust can scarcely be called a processed fuel.

Hogged fuel is produced by wood-hogs and drum-type wood chippers. For the most part the product of these machines is non-uniform in quality, consisting of sawdust, shavings, chips and slivers. There is ample evidence that improvements to these machines are underway and will result in a more uniform product, but presently it is suitable for burning in large installations where uniformity of the fragment is not entirely necessary.

Available, but seldom used for fuel chipping, has been the pulp-mill-type disc chipper, whose product has had to meet exacting requirements of uniformity. Designed for the chipping of round bolts, it was not too adapted for the production of uniform chips from sawmill and other such type waste. The latest models of this machine can convert almost any physical shape of wood to uniform fragments and be set to vary the size of fragment, according to requirements.

Of late, wood hog, drum chipper and disc chipper, have been produced in efficient portable models. This has widened their scope of operation from a purely plant application to the field, and has brought the vast source of raw material such as logging-slash, portable mill waste, wood-lot and forest improvement cuttings and trees of no com-

mercial value into economic being. Such material was rarely utilized because of its bulk per solid volume, making it extremely costly to handle and transport. It can now be processed and loaded on the spot and economically transported and handled.

We can say that we have the equipment available to produce the following grades of chipped fuel: (1) sawdust, (2) hogged fuel, (3) chipped fuel, and that the latter grade can be subdivided into fragments for grades suitable to our purpose. We can also say that the equipment can go any place from which the product can be transported.

Raw Material Sources

Raw material for our purpose is the most abundant of any and there seems to be few places where waste wood in good volume is not available. Logging slash constitutes some 40 percent of useable material, certainly for our purpose, from each tree cut in wood operations. In most cases, this is left behind to rot in the forests, providing a breeding-ground for pests, and a fire hazard that runs into millions annually. Various costs of eliminating this menace to our wealth by slash burning, range upward from $85.00 an acre. Were this bonus alone subtracted from gleaning operation costs by fuel chipping, such operations would be very attractive. Where relatively local markets are available and acreage coverage is average, culls as well as slash processed, a good return can be expected. By the installation of chip-burning equipment the wood-lot owner and population living near forested areas could greatly benefit from this source. Conditions vary greatly but in the average it has been found that chips from this source can be produced and transported for $5.00 a dry ton in operations covering a 50-mile radius.

By far the most available source of raw material for chipped fuel are the permanent and semi-permanent sawmills dotted across this continent. There the material has been brought to transportation. There are many surveys covering "waste" material from this source showing over 30 percent of every log sawn to be converted to slabs and edgings and 3 percent to firewood and refuse—all good raw material for our purpose. Such bulk of material may be obtained from efficient sawmills; a greatly augmented figure is given for portable and small installations. A recent trial of a portable chipper operating at portable sawmill sites showed that cost of chipping and transporting over a 50-mile radius could be carried out for as low a figure as $3.10 a dry ton. In most cases the waste from sawmills is sold for an extremely low figure, in many cases given away or left to rot.

We have vast areas in this country, readily available to transportation, covered by fast growing species considered to be "weed trees" because they have no known commercial value. They are perfectly suitable to our purpose. It would be economical and desirable to "clear-cut" this acreage and use part of the profits from this type of venture to reforest with more desirable species, for the use of future generations.

The New England States are considered quite high in the utilization picture, yet various estimates show that some 300,000 tons of totally unused sawmill waste is annually available from that source. The Chief of the Forestry Co-operation Section, State of New Jersey, long noted as in the forefront of utilization of forest products, reports for 1950 that "total cut of New Jersey grown saw timber, piling, furnace poles, basket logs and round poles was 26,000,000 board feet, Doyle rule. Wastage in limbs and tops will run 1.5 cords per M board feet down to a 4-inch diameter. To a 1-inch diameter (suitable to our purpose) it would probably run 1.8 cords per M feet."

We have heard and will hear at this conference of the relative values of chipped wood for fuel and of the equipment available to burn it. It would appear that with a tremendous volume of raw material wasting in the field and at plant sites, it should not be too difficult, as the facts become more generally known, to bring back wood to its rightful place in modern heating economy and at the same time to utilize some of the material we so prodigally waste.

Use of Wood Fines in Gravity Feed Stoves

JOHN W. ALLEN, *Assistant Technical Director, Institute of Forest Products, State of Washington*

A review of the use of wood fines as fuel in gravity feed stoves in the Pacific Northwest and a brief discussion of methods of producing wood fines suitable for gravity feeding.

Introduction

THE anticipated demands on fuel oil, coal, natural gas and hydroelectric power for the current defense program and the curtailing of these items to the public could result in acute fuel shortages. A review of the uses of wood fines as fuel in domestic furnaces, water heaters and kitchen ranges merits consideration.

The gravity feed stove for burning wood fines is simply a combustion chamber, sometimes called a Dutch oven, attached to the fire-box of a conventional furnace, kitchen range or hot water heater. A supply of fuel sufficient to last several hours is contained in a hopper which permits the fuel to fall to the grates of the Dutch oven at the rate of burning. The fuel is clean and inexpensive, costing today 40 percent less than fuel oil for home heating, and utilizing wood that might be disposed of otherwise as a nuisance.

This domestic fuel outlet is worth more than one million dollars per year to the fuel dealers of the Pacific Northwest. Moreover, it is reducing demands on fuel oil supplies by thirteen million gallons per year.

Use of Gravity Feed Stoves in the Pacific Northwest

Gravity feed stoves, commonly called sawdust burners, became popular in the Pacific Northwest in about 1924. Sawdust was cheap, plentiful and of good quality. The burners were quite successful. By 1929 so many units were in service that during the coldest months the supply of sawdust was insufficient and some users went without fuel. The demand for sawdust underwent a rapid change within a few years. At one time the sawmills paid truckers to haul away and dump whatever residuals they could not handle in their "waste burners". When sawdust burners first appeared, the mills charged the truckers about 10 to 15 cents per 200-cubic-foot unit at the mill. The price has steadily increased until now it is about one dollar per unit.

Trucking costs are high for this bulky material whether it is hauled loose in a stake-body truck or in sacks of four cubic feet each. A truck will take 150 sacks or 600 cubic feet of loose sawdust. With truck operating costs of about $7.00 to $8.00 per hour, deliveries are limited to distances of about 15 miles from the mills. A truck and driver can average four sack deliveries or eight blower-truck deliveries per day.

The cost of sawdust to the consumer, blown into the basement, has risen from about $3.00 per unit to around $7.00 per unit. One unit will heat a six-room house for one month in average winter weather on the West Coast.

The clean, economical heat was popular at first, especially when costs of oil burner installations were two or three times what they are now. In the 1920's the conventional furnace could be converted for sawdust burning for about $30.00. Today the cost is about $80.00.

Little attention was required for the gravity feed sawdust burners. This was a big advantage over the hand-stoked wood and coal burners which require frequent firings. The cost of completely automatic feeds in those days was out of reach of most of the people, so the sawdust burner furnished the best heat for the least money. The hopper, with a capacity of five to nine cubic feet, needed filling but two or three times a day. Ashes, cleaned out once a week, amounted to scarcely a handful.

The major obstacle to a greater use of sawdust burners was lack of a year around supply. When the demand was at its peak in the winter, the sawmills also had their greatest need for fuel and could not release sawdust to the fuel dealers. The fuel dealers, having limited storage facilities, mostly uncovered, could do little to allay the demand. Efforts to have consumers devote enough basement space to the storage of four to six units, 800 to 1200 cubic feet, were mostly unsuccessful.

After a few cold winters, fuel dealers built up large storage areas and strove to convince the public that it should store sawdust in the summer when the supply was plentiful. Recently a fuel company sent out an appeal for cooperation with the guarantee that for every unit the customer stored in the summer, the dealer would guarantee delivery of an equal amount in the middle of the winter. This assured those who would store sawdust in the summer of having an ample supply in the winter. The plan worked and helped to reduce the dealer's storage problems.

Another means of increasing the supply of fuel for domestic sawdust burners during winter months was to screen the fines from hogged fuel. Hogs were set fine, perhaps even replacing the bearings to obtain good adjustment and assure a small chip. The chips were screened by passing them over a vibrating steel sheet with punched holes one inch in diameter. The fines falling through were then delivered to the sawdust bins. The sawdust and screened chip combination was marketed as half-and-half, although the ratio of chips to sawdust varied considerably in any individual load.

Extending the supply of winter sawdust by outside storage, home storage and random addition of chips did not solve the problem completely. The indiscriminate use of any species or quality of fines during the period of heavy demand, caused much dissatisfaction. Many people began to change over to oil burners at the end of the depression. Money was more plentiful, oil burners were being produced in larger numbers and the installation price had decreased considerably. During 1934 and 1935 the changeover went on rapidly. People seemed willing to pay a premium for the oil fuel to get away from the nuisance and the labor involved in handling sawdust. The furnace companies pushed the sale of oil burners because installation income was greater than with sawdust burners. Consequently, since the end of the depression, very few sawdust burners have been sold.

The fuel companies and the mills in Seattle, not wanting to lose the sawdust trade combined forces to set up a sales agency and keep sawdust burners on the market. While partially effective, the trend toward oil fuel continued. By 1939, the sales association was no longer functioning.

Since 1939, installations of sawdust burners in the northwestern United States have been mostly second-hand units. This is not true in British Columbia, where high costs of oil burner installations, the high cost of oil, a scarcity of oil burners and a very good wood fuel distribution system have operated to keep sawdust in a prominent place. For one large Vancouver company, the domestic sawdust business is worth $150,000 per year. However, the general trend today in the Pacific Northwest is the removal of sawdust burners and their replacement with oil burners.

The Gravity Feed System

A continuous supply of fuel for the Dutch oven burner is supplied by a hopper. The hopper must pass fuel to a grate ten inches wide in some furnace units or to grates four or six inches wide in kitchen ranges and hot water heaters. To provide storage capacity, the hopper is flared out above the delivery point. Where the flaring out occurs, the troubles of gravity feed systems are concentrated. The weight of the fuel causes a pressure in this space, and a tendency to wedge.

For efficient feeding, the throat width of the hopper should be almost the same as the width of the grate, thus depositing a uniform layer of fuel over the grates.

Because the weight of the sawdust is directly on the horizontal grate, the fuel feeds only as fast as it burns. To regulate burning therefore, the controls must be on the flue damper and grate draft. An automatic thermostat to regulate the draft is available for about $20.00.

The hopper is hinged to permit access to the burner for cleaning purposes and for laying a new fire. An agitator or pressure eliminator is suspended in the hopper to prevent the fuel from arching over and hanging-up. The small units for kitchen ranges and hot water heaters generally have no agitators. It has been found that a round hopper will feed rough-cut fines better than will a rectangular hopper.

When hang-ups occur, they are caused usually by chips which have fallen in such a manner that they tend to form an arch and they are held tightly in the arch by the weight of the material in the hopper above. Fuel that is too wet packs the throat tightly and will cause a hang-up. Long slivers, reaching clear across the throat, will cause hang-ups very quickly as will dry fuel lacking the weight to prevent the ashes from arching and blocking feed to the grates. The fire then will burn up into the hopper filling the house with the persistent smell of smoke and wood distillate. When the arch has burned out, the sudden release of sawdust will smother the remains of the fire. The gases above the smothered fire will ignite when the fire burns through the new fuel-bed and blow back with a bang. This blow-back tendency discourages some home owners from using sawdust burners. When a fire is actually smothered so that it goes out or when a fire is shut down for considerable periods, the flue pipes cool down. The wood distillate condenses in the pipes as well as on the door of the draft and in the throat of the hopper. The distillate will corrode the metal and necessitate frequent cleaning of the flue pipes and the hopper throat. Replacement of the flue pipes may be required every few years. The hang-ups, largely offsetting the advantages of the gravity feeding system, have been the object of much study looking to their correction.

A prime consideration is the size of the fuel in relation to the size of the throat through which it must pass. For the small units with throat widths of less than ten inches, the fines must not exceed the size of coarse sawdust. One-quarter inch cubes approach the maximum size. Because of the feeding difficulty in the small throats on kitchen ranges and hot water heaters, much care is taken to reduce the chances for hang-ups. Frequent cleaning and polishing of the throat and the hopper, using a lye solution to clean, rags to polish and hard wax or powdered graphite to reduce friction are standard practices.

For furnace units with throats over ten inches wide, the maximum size of fines runs to three inches long and one inch square but the pieces over one-quarter inch square should not exceed fifty percent. The remainder should be fines of the consistency of sawdust with the ability to flow.

Some hoppers have a one-inch mesh screen set across the top to screen out big chunks, stringy material and slivers all of which are potential hang-up producers. The screen also breaks up tightly packed fines and delivers only loose free fuel to the hopper.

If the proportion of large chips is excessive and the hopper lid is not tight, air will come down to the grates through the hopper. The extra draft, thus caused, may be enough to keep the fire burning quite briskly, wasting fuel and perhaps keeping the house too warm. If the fuel is too light in weight, like shavings, it will not settle in the hopper and the fire may burn up into the hopper. When light-weight fuel does reach the grate, the draft may lift it into the combustion chamber, where it will pass off into the flue in a half-burned condition. Storage in a basement for a few months can dry fines out so that they burn too fast but wetting periodically can prevent this. If the fuel is too wet, however, it will cake and will not feed.

To insure positive feeding, oversize grates have been used with a correspondingly big hopper throat and a high furnace heat output. Extra-large wood particles may be fed into this type of unit. However, the heat generated is excessive so the furnace may be shut off for long intervals causing excessive condensation of distillate when it is started again. Also, the fire has a chance to work up in the hopper.

Designed to assure continuous feed, some gravity units feed a spiral-conveyor. The throat then could be rectangular, twenty to thirty inches long, but limited in width to that of the conveyor. With a practical spiral-conveyor of three to four inches in diameter the width is so narrow that the fuel arches over very quickly so this system is not entirely successful. A model could be built with a spiral-conveyor feed of twelve or fourteen inches in diameter operating out of a conventional hopper, but the expense involved might be too high to justify its use.

In 1931–1932 Professor Bror L. Grondal of the College of Forestry, University of Washington, developed a hopper unit to do away with hang-ups, provide a uniform combustion and accommodate a wide range of fuel sizes. This hopper had a very spacious throat under which a belt with wooden cleats operated, conveying the fines directly into a turning spiral-conveyor. The latter in turn, fed the grates of the combustion chamber. A forced draft control was connected in a manner that would control the belt conveyor and the spiral-conveyor feed. The unit worked out fine. There was no place for hang-ups to occur. The expense of this hopper feed system, however, added $100.00 to installation charges, and was priced out of the market.

Some feed troubles are induced by the owner through his failure to keep the hopper clean or to screen the fuel; or through shoveling packed fines into the hopper and tamping the fuel down into the throat which packs the fines and increases the probability of arching.

Quality of Fuel Available for Gravity Feed Stoves

Sawdust from circular saws provided the first fuel for gravity feed stoves. These fines were rough kernels ranging in size from about one-quarter of an inch square for the bigger particles, down to extremely small material. The species used was almost entirely old-growth Douglas fir averaging about 40 percent moisture content. Gravity feeding of this small cube-like wood interspersed with very fine particles, was excellent.

When greater demand caused temporary shortages of sawdust, screened chips were introduced. The chips were flat and rectangular and would not feed through the throats of the small hoppers used on kitchen ranges and hot water heaters. The throats of the small units ranged from four inches to six inches in width. This material would feed well in furnace hoppers with throat widths of ten inches or wider. Some consumers considered the steady, slow-burning chip mixture more suitable than straight sawdust for the larger units.

The increased sawing of species like hemlock with its extremely high moisture content, cedar with its light weight and fast burning characteristics, and second-growth Douglas fir with its high moisture content, lowered the average quality of sawdust. Some dealers mixed shavings in and found them too light to pack and feed. The consumer never was sure of what he was getting and he often received a poor burning mixture. The half-and-half mixtures were sometimes mostly chips which caused hang-ups in the hopper. Screened chips up to 75 percent fed all right in a ten-inch throat with a round hopper.

When the sawmills began changing over to band saws producing a long narrow chip instead of a cubical one, gravity feeding became a little more difficult because the elongated chips tended to hang up more than did the cubical chips from circular saws.

Moisture content of wood fines is very important in determining their ability to feed. Fines with moisture contents up to approximately 47 percent will feed in a small hopper. Fines with higher moisture contents will hang up. Fuel companies, attempting to use uncovered storage, have delivered extremely wet fuel which caused feeding troubles and poor burning, and yielded less heat per unit.

When pulp mills began to buy sawmill residuals in quantity for pulp chips or steam generation many sawmill owners lost interest in the domestic fuel market. The sales of fines for industrial fuel made

big inroads on the supplies available at sawmills. However, there are still large quantities of mill residuals at small outlying sawmills that may be had for little or nothing.

The increased utilization of poor-quality logs laden with rot and insects, has provided doty, wet sawdust containing a multitude of insects. The insects, which have been introduced to the homes of the consumers, include fleas, spiders, flying ants and termites.

With so many changes in the types of fines developed incidental to the production of lumber and with most of the changes resulting in poorer feeding fuels, the need of high-quality fines for gravity feed stoves prompted the development of cutting or sawing machines that could make a suitable fuel. The ideal particle was more or less cubical and came from a circular head saw.

Fig. 1 is a photograph of sawdust created by a circular saw cutting a Douglas fir slab.

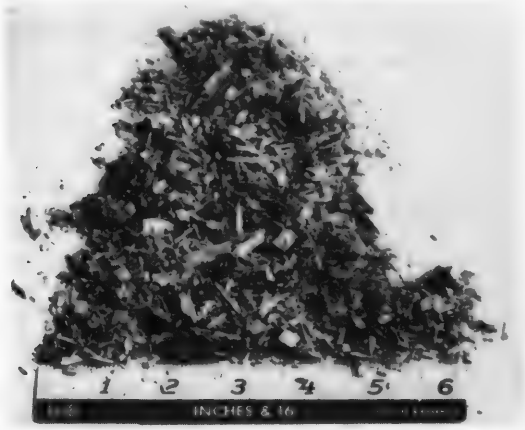


Fig. 1.—Wood fines, produced by a "sawdust machine", are suitable for feeding in all gravity feed hoppers.

Chips, made by a disc chipper or a hog, can be cut to the same mass as the chips created by the circular saw but they will not be cubical. They are flat and rectangular as shown in Fig. 2. There will be insufficient fine, dustlike particles and the chips will not feed by themselves in a hopper whose throat is under ten inches in width even though the chips are as small as the chips in rough-cut sawdust. Extremely fine material must be present to feed in the small throats.

Commercial wood hogs, portable chippers, bone shredders, sawdust granulators, disc chippers and other units that cut with a knife action either make a flat chip or a shaving, even with serrated knife edges. The material from all of these machines will not feed through a four-or-six-inch throat without the small fines. Also, to make a small chip or shaving with some of these machines, the capacity is reduced to where they may not be economical to run. The "sawdust granulator" a disc type chipper

Fig. 2.—Chips from a portable chipper were mixed with 25 percent sawdust to feed through a ten-inch throat. They would not feed satisfactorily through four- and six-inch throats.

costing about $5,000.00 with a capacity of four units per hour of extremely small chips, turns out a fuel that will feed very well in hoppers with throats over ten inches wide but to feed in the smaller hoppers fine sawdust should be added.

Where a supply of sawdust is not available to combine with chips and improve flow characteristics a "sawdust machine" may be used. It will turn out sawdust of excellent quality that will feed in any hopper. The "sawdust machine" is a battery of 16 to 24 circular saws mounted on a common shaft with the saw collars slightly askew from a normal to the axis of the common shaft. The slight turning of the collars forces the saws to cut a wide swath for a kerf nearly completely consuming the slabs and edgings fed through the machine. The saws are called wobble or drunken saws. They are powered by a 100-horse power electric motor and are fed by

Fig. 3.—Chipped logging debris must be carefully screened and mixed with about 40 percent sawdust to feed in the largest gravity feed stoves.

powered feed rolls, with an output of 18 to 20 units per eight-hour day. The speed of the saws and the feed rolls determine the coarseness of the sawdust. This machine can be built in a machine shop for about $1,500.

If the fuel available is of good heating value, has a reasonable moisture content (up to 50 percent) and can be converted to sawdust form it will feed and burn satisfactorily.

Chips from logging residuals generally have a high moisture content, due to a high sapwood percentage and unless predried will yield little heat. If branches are included, the small twigs tend to pull through without being cut (see Fig. 3) thus causing hang-ups.

Conclusions

The use of chipped wood in gravity feed stoves is satisfactory when the chips are cubical ranging from one-quarter inch down in size and made up of a good percentage of the very fine material which has desirable flow characteristics. Stoves with grates over ten inches wide, such as would be used for a furnace unit in a six-room house, will feed much larger chips but at least 25 percent of the fuel volume must be in small fines that can impart good flow characteristics to the large chips.

There is available machinery and screens to produce the desired fines for feeding in gravity feed systems. They are not expensive and they have large capacities.

To promote the use of the gravity feed stoves in the home is the most difficult problem. The continual hopper cleaning and polishing, the space needed for storage, the insects, the smoke and blowbacks and the nuisance of filling the hopper when added up tend to overbalance the saving on the fuel bill for the American home owner.

Discussion

Mr. John Henry Jenkins (Canada Forest Service): The use of sawdust for domestic heating is not practicable unless a 12-months supply can be guaranteed. A promising possibility is the use of suitably chipped wood for logging camps. Such installation should preferably be in a furnace for central heating of a group of buildings, or even one H-type building. The filling of a sawdust burner on a stove within a bunk house might cause an objectionable dust. Therefore some form of central heating is suggested with the furnace outside the bunkhouse. We are planning further work along those lines.

Mr. Edgar L. Heermance (Northeastern Wood Utilization Council): The Council is working with the Canadian Pulp and Paper Research Institute on the possible use of portable chippers to supply fuel for logging camps. None of us like to see pulp companies shifting to oil for fuel. Since a great deal of interest in chipped wood has followed our conference at Marlboro, Vermont, last September, and so much development is going forward, Mr. Koroleff has urged another meeting of workers in this field. We have arranged to hold such a meeting in New Hampshire early in July.

Mr. Richard A. Hale (R. H. Hale Logging & Lumber Company): What does it cost to deliver wood in chipped form?

Mr. Alexander: Our tests indicate that the cost of chips from slabs and polewood from a 25-mile area, allowing 18 cents a cord-mile for transportation, averages $3.10 per stacked cord equivalent. The initial cost of slab and polewood before chipping should be added.

Mr. Hale: What is the maximum moisture content suitable for operation of a sawdust burner? Can green chips be burned satisfactorily?

Mr. Allen: Yes, although of course the fuel value is reduced. A moisture content above 50 percent is not desirable.

Mr. Alexander: Chipped wood is superior to sawdust, because you do not have dust. Sawdust, when obtainable, although cheap, is a by-product of and tied to sawmill cutting schedules, whereas raw materials for chipped fuel may be obtained from slash, uneconomical weed woods and other such sources as well as from mill waste. One point I'd like to emphasize is the importance of grading your chips, according to the use to which they will be put. Our company has been working on that. Chips that will make satisfactory mulch are not fine enough for cattle or poultry bedding. Coarse uneven chips, that would feed in the spreader stokers that Mr. Miller is about to describe, will not answer for gravity feed stoves and furnaces. For that use, the chips must be small and uniform, and such fuel requires a portable chipper of the disk type.

Mr. Allen: Quarter-inch chips feed well in the hoppers of standard sawdust burners. They should, however, be cube-shaped rather than flat, or there is a tendency for the feed to clog. In a disk chipper, it is possible to do this by a proper adjustment of the knife setting.

Mr. Alexander: Methods used for governing the physical shape and size of fragment, in order to obtain the desired grades of chipped wood from power-fed inclined disk chippers, are as follows:

(a) Fiber Length (length along the grain vs. length of chip.)—Wearing plates, set in the disk face ahead of the knives, are moved in and out in relation to the disk face, widening or narrowing the interval between disk face and knife edge, by means of jacks. The feed rate differential is altered to synchronize with the interval chosen, thus obtaining accurate lengths of fragment. (b) Thickness—The angle of the knife edge in the disk knives determines chip thickness. Standard 1/4 inch thickness is obtained at 37 degrees. Increase of angle makes thinner chips, decrease of angle thicker chips. (c) Width—Although not necessary in average applications this can be controlled by two methods: Serrated disk knives or card breakers.

Spreader Stoker Firing of Wood and Coal in Multiple Fuel Furnaces

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The advantages of spreader stoker firing of wood in combination with other fuels is discussed. The design of the stokers, furnaces, and auxiliary equipment for multiple fuel firing is explained. The effect of moisture content of the wood on steam capacity and efficiency is shown.

Introduction

THE selection of steam generating units, designed for burning several fuels, is becoming a common practice because such units have an advantage in the changing picture of fuel price and fuel supply. The transitory nature of availability and price of fuels should be a basic consideration in the engineering of new steam generating units. In many parts of the country wood refuse should be considered in fuel studies because where wood is available, it is frequently the most economical fuel. The interchangeable unit, capable of burning wood as well as oil, coal, or gas, is highly desirable.

During the past fifteen years there has been a swing to the spreader stoker furnace for multiple fuel firing. This trend has been brought about by improved efficiency, reduced maintenance, and the adaptability of the spreader stoker furnace to the burning of various fuels. The spreader stoker, consisting of a grate and distributing device, can be adapted to fire nearly all of the solid fuels. The spreader is the most popular type of firing for solid fuels in the size range of 10,000 to 200,000 pounds of steam per hour. Many spreader stoker units burning coal and wood are also equipped with burners for oil or gas.

The spreader stoker is one in which the fuel is scattered, or spread, over the burning fuel bed. In this process the heavy particles fall to the grate and burn while the small particles quickly ignite and burn in suspension. It may be misleading to refer to the fuel bed because the layer of fuel is very thin, usually being no thicker than the largest particle of fuel. The very thin fuel bed and suspension burning produce a fire that responds rapidly to feed rate changes. With proper control of fuel and air, the rate of combustion can be made to follow steam load changes very closely.

A large portion of the air for combustion, 75 percent to 95 percent, passes through the grates and the remainder is used in furnace turbulence, reinjection of flyash, and distribution of the fuel. The air passing through the grates cools the grates and the ash which accumulates on the grates and beneath the burning fuel. Since the ash is deposited beneath the burning fuel and is continuously cooled, the ash remains granular and remarkably clinker free.

Multiple chain drags or multiple worms in the bottom of the storage hopper are the most favored feeders. Either of these types can be driven by variable speed drives for the control of wood feed rate. The problems involved in preparing for dual firing and the success of the system has recently been described by Turner (*1*).

A simplified form of the spreader has been developed for use in conjunction with oil and gas (Fig. 1). The wood is fed into the furnace wall

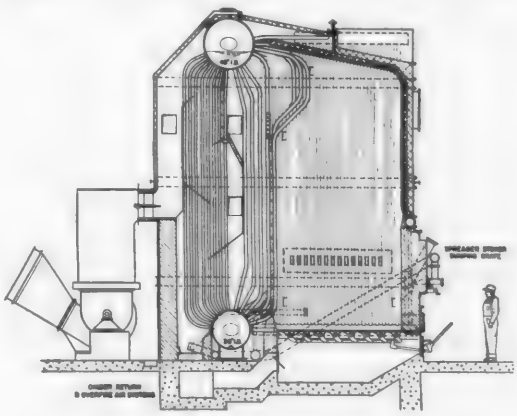

Fig. 1.—Combination gas-and-wood-fired boiler, 50,000 lbs. steam per hour.

and is distributed over the grate by high velocity air jets located at the base of the chutes.

This system of firing works equally well with coal and hogged wood. The basic equipment necessary for coal firing can readily be adapted to handle wood. Another type, the spreader stoker with the over-running distributor is ideally suited for interchangeable units in which coal and wood are to be

burned alternately. The fuel is fed at a regulated rate from the base of the hopper and into the path of the rotating distributor blades which spread the fuel over the grates. The feeding and regulating device for coal is built integrally with the distributor.

It is the feeding and regulating devices which must be changed for wood firing. The volume of wood that must be handled, ten times that of equivalent coal, and the tendency for wood to mat in hoppers, make the use of the coal feeding device impractical. A feed regulating device designed for the requirements of wood must be provided.

Grates

The grates for a spreader stoker can be of three types: stationary, dumping, or traveling. The stationary grate is the simplest, and is one from which the ashes must be hoed manually. The dumping grate is arranged so that by tilting the grate surface the accumulated ash is dumped into a pit beneath the grate, with the pit serving as a plenum chamber and ash pit (Fig. 1). Stationary and dump grates are arranged in multiple sections so that the boiler load can be maintained while the sections are cleaned one by one. Grates with two sections may lose 10 percent to 25 percent of the load during cleaning but grates with three or more sections need not lose load during cleaning.

The traveling grate is an assembly of many small grates attached to chains which pull the assembly slowly through the furnace, continuously discharging the ashes into the ashpit. The cost of installing a traveling grate as compared to a dumping grate discourages the use of traveling grates in small units. Dumping grates may be used for coal-and-wood units with capacities up to 50,000 pounds of steam per hour, and if no coal is to be burned, dumping grates can be used for capacities up to 100,00 pounds of steam per hour. Beyond these limits traveling grates should be considered because of reduced operating labor and improved efficiency. Traverse zoning of traveling grates permits extreme load ranges. Units of the type shown in Fig. 2 have performed at continuous loads of from 8,000 to 220,000 pounds of steam per hour when operating on wood with 49 percent moisture. Fifteen to one load variations on coal are also obtained.

The three types of grates have certain features in common. Since the ash and fuel beds are thin and porous, the grate must offer resistance to air flow to assure air flow to the entire active grate area. Usually spreader stoker grates have from 3 percent to 5 percent of the grate area open for air passage as compared to 20 percent to 30 percent openings in the inclined and flat grates used in Dutch oven type furnaces.

Furnace Design

The furnace design for spreader stoker fired units should be liberal. Heat releases of 35,000 Btu. per hour per cubic foot of furnace volume will give

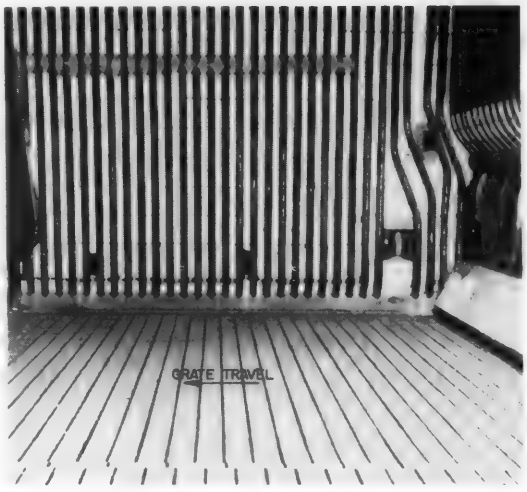

Fig. 2.—Water-cooled furnace, 250,000 lbs. steam per hour—wood and coal—traveling-grate spreader stoker.

acceptable results, but units designed with furnace volume below 25,000 Btu. per cubic foot per hour will give improved efficiency and will reduce flyash. It must be remembered that in a spreader stoker furnace, many particles are held in suspension by the furnace gases, and unless the furnace volume is such that ample time is provided for burning, a high percentage of the burning particles will get into boiler heating surfaces before they are completely burned. A well designed spreader-stoker wood-burning furnace is ideally suited for burning coal, oil, or gas. Comparative ratings obtainable from three fuels on a typical unit are shown in Table 1.

Water cooling of the furnace walls is essential for optimum efficiency and minimum maintenance. This surface, absorbing heat by radiation, is the most effective of the heating surfaces in a steam generating unit. The proper design of the furnace walls will almost completely eliminate furnace refractory maintenance. Only with water cooled furnaces can coal be burned efficiently and trouble-free, because the high burning rates and low excess air common in modern units would cause severe slagging of the walls of refractory furnaces. Furnace cleaning and refractory maintenance in furnaces of the type shown in Fig. 2 are rarely experienced. No less demanding of water cooling is the hogged wood which contains salts and marine growths from logs that have floated in salt water because these forms of extraneous ash rapidly attack bare refractory walls.

Furnace Turbulence

Optimum performance of spreader stokers can be obtained only by the application of jets to create furnace turbulence, which is otherwise lacking in the archless furnace of Fig. 1. Properly designed and operated wood-burning, spreader-stoker units are noticeably free of smoke. As shown by a num-

TABLE 1.—COMPARATIVE DATA FROM MULTIPLE FUEL SPREADER-STOKER UNIT

	Wood Wood 49 percent Moisture	Coal Coal 12,500 Btu.	
Rated capacity steam generated Lbs. per hour	175,000	240,000	240,000
Furnace heat release Btu. per cu. ft. per hour	21,500	23,400	23,000
Induced draft fan requirements—Lbs. flue gas per hour	331,000	327,300	305,000
Forced draft fan requirements—Lbs. air per hour	270,000	300,100	280,000
Efficiency	66.5	82	84
Fuel cost delivered	$2.00/200 cu. ft.	$10.50/ton	$2.45/bbl.
Fuel cost per 1,000 Lbs. steam	$0.19	$0.58	$0.45

ber of investigations, the turbulence system is equally important when burning coal.

Turbulence can be obtained from steam jets or air nozzles. When using steam for turbulence, one to two percent of the total steam production will be required. Where make-up water for boiler feed is a problem, steam for turbulence may not be practical. High velocity air nozzles are generally accepted as the most desirable form of turbulence for wood firing. The fan capacity should be selected to deliver approximately 15 percent of the air required for wood firing, with static pressures of from 10 to 30 in. water gauge.

Flyash

Grate size, furnace design, and flyash collection can be arranged to maintain low flyash emission from the stack. When selecting grate sizes, consideration must be given to flyash problems. It can readily be seen that the amount of particles carried will increase rapidly as the gas velocity of the furnace increases. From the standpoint of grate performance, the stoker will operate equally effectively at grate heat release of half a million Btu. per hour per square foot of grate area or at three-fourths million Btu. per hour per square foot of grate area, but this increase of 50 percent in burning rate will more than double the amount of flyash. An HRT boiler with spreader stoker, when operating with a top burning rate of 350,000 Btu. per hour per square foot of grate, will satisfactorily operate without dust collection. Most units, such as shown in Fig. 1, operating in excess of 400,000 Btu. per square foot per hour should be equipped with cinder recovery equipment, in order to reduce the quantity of solids discharged from the stack and to improve efficiency by recovery of the solids. Dust loading of wood burning spreader stokers compares favorably with Dutch oven furnaces, but is higher than the dust loading of coal-burning spreader stokers. The wood flyash has larger particles than does flyash from coal.

Moisture in Wood

The moisture content of the wood to be burned is an important consideration in the engineering of wood-burning units. The moisture content of wood affects the overall efficiency of the steam generating unit, and it also affects the burning characteristics of the wood, each of which bears a definite relation to the steam producing capacity of any specific steam generating unit. High wood moisture contents affect burning characteristics to such a degree that wood-burning units may become very demanding of the operator's time.

The term "moisture content" may be expressed in two ways. Wood technologists report the moisture content as a percent of the dry wood weight. For example, when one pound of bone-dry wood is combined with a half pound of water, the moisture content is expressed as 50 percent. Engineers commonly express the moisture content as a percent of the total weight, as for example, when a half pound of wood is combined with a half pound of water, the moisture content is recorded as 50 percent. It is the latter method that is most commonly accepted when speaking of fuels, and it is the method which will be referred to in this paper.

An increasing moisture content retards combustion and lowers the flame temperature but this does not seriously affect operation until the moisture exceeds 45 percent. Somewhere between 65 and 70 percent moisture these two factors combine to create a condition in which the fuel will no longer produce a stable fire. Some authorities have given limiting moisture content as low as 63 percent while others refer to figures as high as 75 percent. These differences can be explained by variations in furnace design and by practical operating limits which are subject to considerable personal opinion. It must be understood that theoretical flame temperatures are never attained in a commercial application, principally because of the nature of the heat absorbing surfaces to which the flame loses heat by radiation. As the moisture content increases, the flame lengthens and an even greater portion of the heat is released in the secondary furnace. In an open furnace all of the heat is released in the presence of heat absorbing surfaces. Fig. 9 illustrates the drop in theoretical flame and furnace temperatures occasioned by the moisture in the fuel.

Although the difference between 65 percent and 75 percent may seem small, it may be the margin by which the wood becomes an economical fuel or a troublesome waste product. Numerous presses are available to reduce the moisture content to an acceptable limit, and it is reported that the total cost of reducing the moisture content compares favorably with the increased value of the bark or wood as fuel. Reduction of the moisture content from 70 to 60 percent will increase the steam produced from a pound of dry wood by 25 percent and may increase the boiler rating by 50 percent.

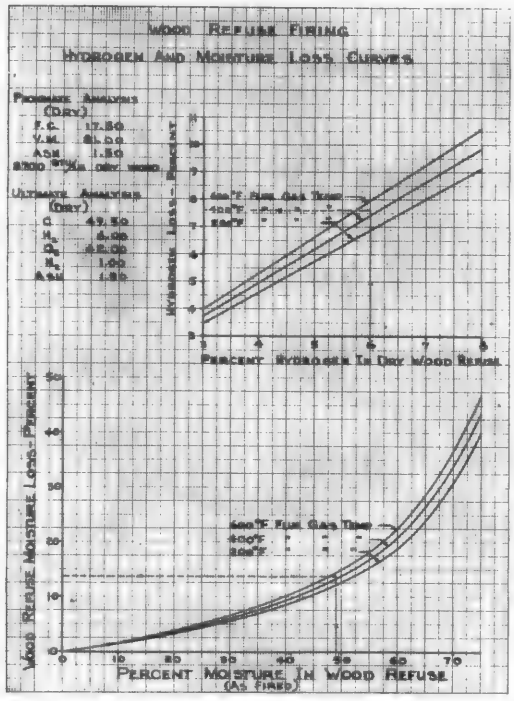

Fig. 3.—Moisture and hydrogen loss.

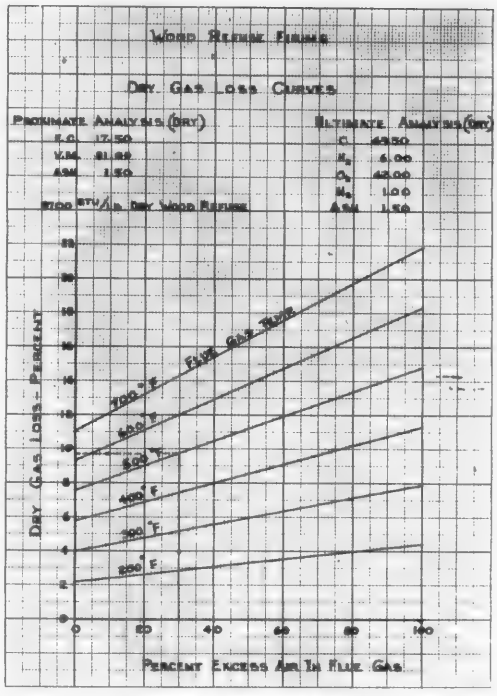

Fig. 4.—Dry gas loss.

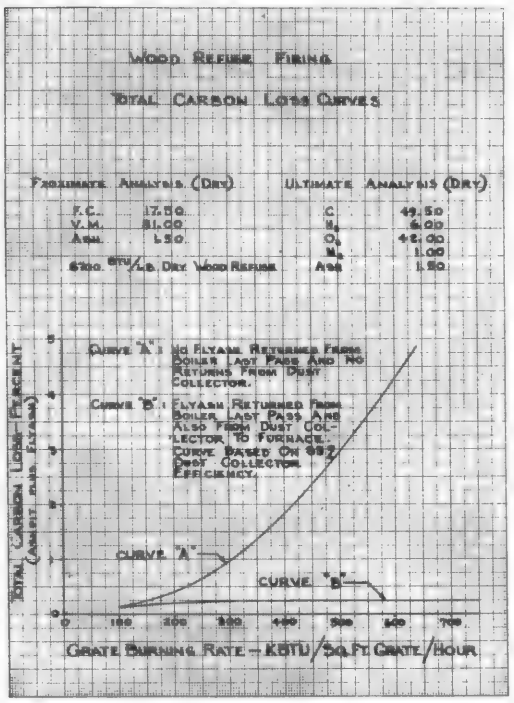
WOOD REFUSE FIRING
TOTAL CARBON LOSS CURVES
PROXIMATE ANALYSIS (DRY)
F.C. 17.50
V.M. 81.00
ASH 1.50
8700 BTU/LB. DRY WOOD REFUSE
ULTIMATE ANALYSIS (DRY)
C 49.50
H2 6.00
O2 42.00
N2 1.00
ASH 1.50
CURVE "A": NO FLYASH RETURNED FROM BOILER LAST PASS AND NO RETURNS FROM DUST COLLECTOR.
CURVE "B": FLYASH RETURNED FROM BOILER LAST PASS ARE ALSO FROM DUST COLLECTOR TO FURNACE. CURVE BASED ON 85% DUST COLLECTOR EFFICIENCY.
TOTAL CARBON LOSS - PERCENT (AMOUNT PASS FLYASH)
CURVE "A"
CURVE "B"
GRATE BURNING RATE - KBTU/SQ.FT. GRATE/HOUR

Fig. 5.—Carbon loss.

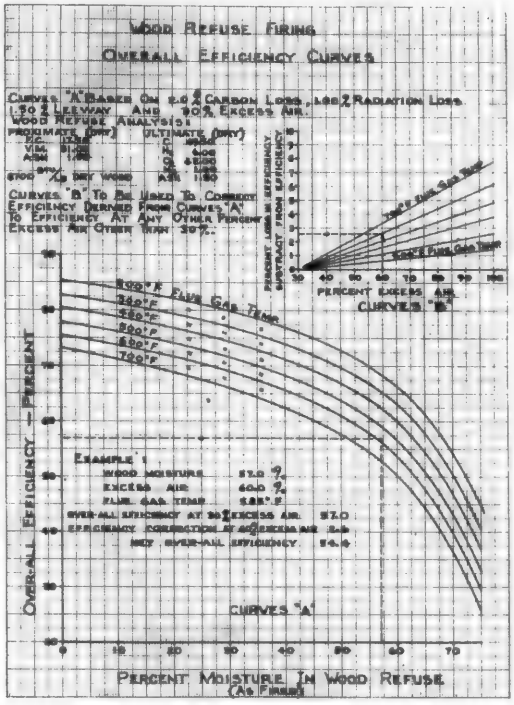
WOOD REFUSE FIRING
OVERALL EFFICIENCY CURVES
CURVES "A" BASED ON 2.0% CARBON LOSS, 1.5% RADIATION LOSS, 1.5% LEEWAY AND 20% EXCESS AIR.
WOOD REFUSE ANALYSIS:
PROXIMATE (DRY) F.C. 17.50 V.M. 81.00 ASH 1.50
ULTIMATE (DRY) C 49.50 H2 6.00 O2 42.00 N2 1.00 ASH 1.50
8700 BTU/LB DRY WOOD
CURVES "B" TO BE USED TO CORRECT EFFICIENCY DERIVED FROM CURVES "A" TO EFFICIENCY AT ANY OTHER PERCENT EXCESS AIR OTHER THAN 20%.
PERCENT LOSS IN EFFICIENCY TO BE SUBTRACT FROM EFFICIENCY
700°F FLUE GAS TEMP.
600°F FLUE GAS TEMP.
PERCENT EXCESS AIR
CURVES "B"
700°F FLUE GAS TEMP.
600°F
500°F
400°F
300°F
200°F
EXAMPLE:
WOOD MOISTURE 52.0 %
EXCESS AIR 60.0 %
FLUE GAS TEMP. 580°F
OVER-ALL EFFICIENCY AT 20% EXCESS AIR 57.0
EFFICIENCY CORRECTION AT 60% EXCESS AIR -2.6
NET OVER-ALL EFFICIENCY 54.4
CURVES "A"
OVERALL EFFICIENCY - PERCENT
PERCENT MOISTURE IN WOOD REFUSE (AS FIRED)

Fig. 7.—Efficiency.

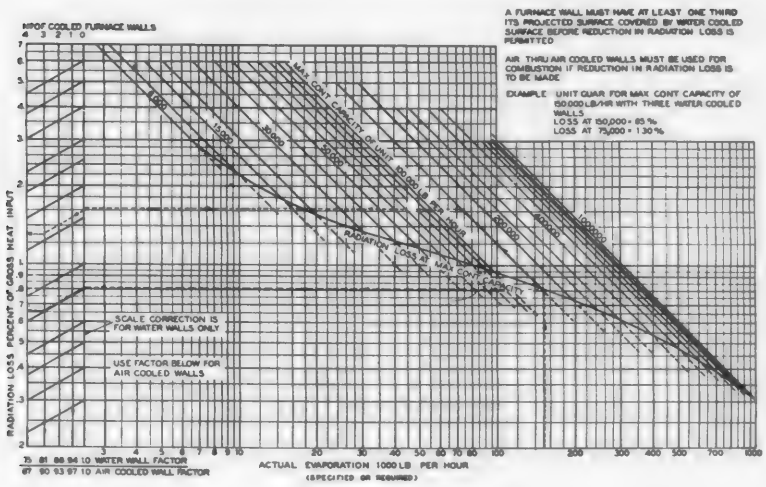
A FURNACE WALL MUST HAVE AT LEAST ONE THIRD ITS PROJECTED SURFACE COVERED BY WATER COOLED SURFACE BEFORE REDUCTION IN RADIATION LOSS IS PERMITTED
AIR THRU AIR COOLED WALLS MUST BE USED FOR COMBUSTION IF REDUCTION IN RADIATION LOSS IS TO BE MADE
EXAMPLE UNIT GUAR FOR MAX CONT CAPACITY OF 150,000 LB/HR WITH THREE WATER COOLED WALLS
LOSS AT 150,000 = 85 %
LOSS AT 75,000 = 1.30 %
SCALE CORRECTION IS FOR WATER WALLS ONLY
USE FACTOR BELOW FOR AIR COOLED WALLS
RADIATION LOSS PERCENT OF GROSS HEAT INPUT
ACTUAL EVAPORATION 1000 LB PER HOUR (SPECIFIED OR REQUIRED)
WATER WALL FACTOR
AIR COOLED WALL FACTOR

Fig. 6.—ABMA Recommended Radiation Standards.

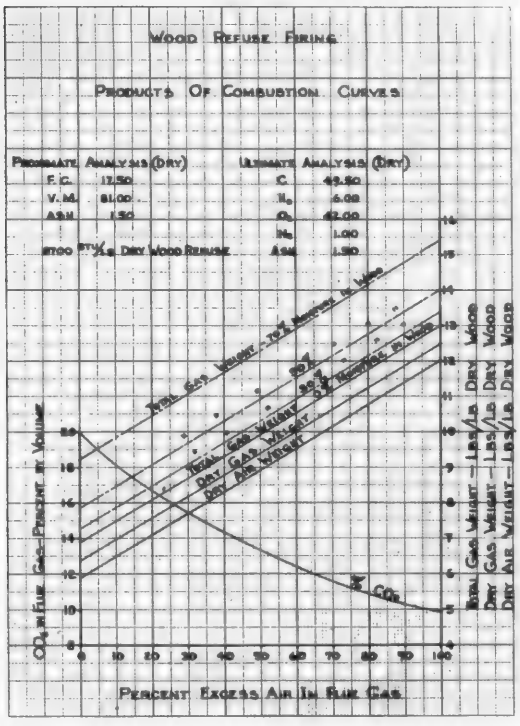

Fig. 8.—Products of combustion.

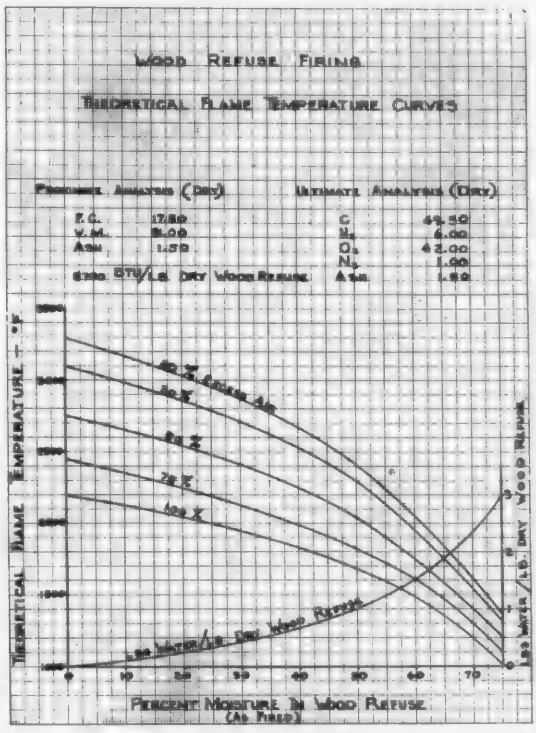

Fig. 9.—Theoretical flame temperature.

The moisture content at which ignition can be successfully and satisfactorily maintained can be increased by the use of auxiliary firing. Where the moisture content is normally satisfactory but occasionally exceeds the safe limit, the addition of oil or gas in the furnace is a very satisfactory means of maintaining ignition. On many units built for dual firing, provision for this method of holding ignition during periods of extremely high moisture is considered desirable. Refractory furnaces or refractory shielding of water wall tubes will improve operation with very wet wood but, like the use of auxiliary firing, is of dubious advantage in increasing efficiency and rating.

Efficiency Calculations

Two factors characteristic of wood which set it apart from coal, oil, or gas are the quantity of the products of combustion and the high moisture content usually experienced. The higher quantities of flue gases require that ample provision be made for air supply and draft. The comparative performance of wood, coal, and oil for a typical unit is shown in Table 1. Compared to coal, wood with a 50 percent moisture content has 50 percent more flue gas to dispose of. The moisture content of "dry wood" would be considered prohibitively high, if encountered in most of our coals. These two factors combine to give low efficiency as compared to efficiencies obtained from other fuels.

Combustion calculations, necessary to establish efficiency and fan requirements for wood firing, follow the standard procedure for other fuels. Precise calculations can be made by using the ultimate analysis of the particular wood to be used, but a simplified system based on the accompanying curves (Figs. 3 to 7) can be used. The calculations can be used for any type of wood firing because the data are fundamental and are not limited to spreader stoker units. The flue gas temperature data are not shown as these must be established for each individual unit and are a function of the arrangement and amount of heating surface and of the boiler rating.

The anticipated efficiency of a steam generating unit is derived by subtracting the total of the various heat losses from 100 percent as outlined in the following example. Assumed conditions of the example are: unit shown in Fig. 2, 500 degrees F. exit gas temperature, 6 percent hydrogen, 49 percent moisture content in wood, and 30 percent excess air in the products of combustion. It will also be assumed that the unit will be equipped with a dust collector for collecting the flyash and that the flyash will be returned to the furnace and burned.

Heat Loss Due To:		Percent
Moisture in fuel	Curve Fig. 3	13.70
Hydrogen in fuel	Curve Fig. 3	7.60
Moisture in air	Usually not more than	.25
Dry chimney gas	Curve Fig. 4	9.70
CO	(Assume complete combustion)	.00
Unburned carbon	Curve Fig. 5	.25
Radiation loss	Curve Fig. 6	1.00
Leeway and unaccounted for		1.50
Total losses		34.00
Efficiency (100—total losses)		66.00

The individual curves have been combined into an efficiency curve that is very convenient in making preliminary calculations for evaluating fuels. This curve, Fig. 7, based on a conservative 30 percent excess air, will be correct within the allowed leeway for the units illustrated.

Induced Draft Fan

The induced draft fan requirements for interchangeable fuels must be calculated for wood burning. A fan so selected will have 35 percent to 55 percent excess capacity for coal, oil, or gas. This extra capacity is usually reflected in an increased boiler rating for those fuels as is shown in Table 1. The wettest wood with which full load must be generated should be used for calculating fan size. The effect of increased moisture content upon the weight of flue gas and draft loss is shown in the following table of calculations. The first seven items are based on available fuel and the design of the boiler, and the remaining items are to be calculated.

	Normal moisture	Maximum moisture
1. Moisture in wood in percent as fired	32	57
2. Btu. per lb. dry wood	8,700	8,700
3. Pounds of steam per hour (200 psig—220° FW)	30,000	30,000
4. Btu. in steam above feed water (1000 Btu.)	30,336	30,336
5. Flue gas temperature at I.D. Fan. °F.	565	585
6. Total draft at I.D. Fan ins. Water	.80	1.7
7. Excess air percent	30	30
8. Efficiency Fig. 7	69.5	57
9. Pounds dry wood per hour	5,000	6,100
10. Pounds air per lb. dry wood, Fig. 8	7.7	7.7
11. Pounds gas per lb. dry wood, Fig. 8	9.2	10.2
12. Pounds of air per hour, Item 9 × Item 10	38,500	47,000
13. Pounds flue gas per hour, Item 9 × Item11	46,000	62,100

Forced Draft Fan

These fans should be selected to match the induced draft fan and checked against the maximum capacity desired from coal, oil, or gas since these fuels, because of increased rating, will normally require more forced draft capacity than wood. Standard leeways should be applied to both the volume and static pressure. The air requirements for wood can be taken from Fig. 8. Comparative air requirements for wood, oil, and coal are shown in Table 1.

The range of fuels that can be burned by the spreader stoker is not limited to hogged wood and coal. The wide selections of fuels from these two sources establishes the versatility of the spreader stoker. Not only can the spreader stoker burn coal and wood but it can combine these two fuels in furnaces also equipped for oil and gas burning. Proper selection of the stoker, furnace, and auxiliary equipment provides a steam generating unit adaptable to the fuel market for many years.

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6. Otto deLorenzi. Some recent developments in burning wet wood. Mechanical Engineering, September 1949.

Discussion

Ralph H. Bescher (Koppers Co., Inc.): I note that the Eugene, Oregon, installation is built for handling wood or coal and I wonder if less complicated types of spreader stokers are available for firing chipped wood only?

Mr. Miller: A simple system for handling chipped wood only is available in the form of the pneumatic distributor. This is the type shown in the Dixie Pine Products installation.

Mr. Bescher: Could such a stoker be used to fire a dryer?

Mr. Miller: The spreader stoker could be used to fire a dryer. The control set-up would be similar to that used in a coal dryer where combustion is controlled for optimum combustion and the products of combustion are then mixed with air to control the quantity of air and temperature of air for the drying process.

T. S. Veazey, Jr. (Anaconda Copper Mining Co.): Does the pneumatic feed system do away with the Dutch oven?

Mr. Miller: The pneumatic spreader stoker or the mechanical spreader stoker are normally used in open furnaces of the types illustrated. However, the spreader stoker can be installed in existing Dutch ovens. The advantage of installing them in existing Dutch ovens is the saving in revamping the setting to eliminate the Dutch oven. Most Dutch oven boilers are set so low that adequate furnace volume would not be available without using the Dutch oven. Obviously in a new installation, the boiler can be set to provide adequate furnace volume without the use of the Dutch oven.

Bryon Lininger (E. I. DuPont de Nemours & Co.): Is the stoker grate the same for wood and coal?

Mr. Miller: Yes. The grate surface of the spreader stoker is independent of the type of fuel used. Regardless of fuel, the grate surface must have a relatively small percentage of air space.

Mr. Lininger: Is furnace turbulence necessary for wood firing?

Mr. Miller: Yes. The furnace turbulence is as necessary for wood firing as it is for coal firing.

James A. Gould (Pratt, Read & Co.): At our plant we have an intermittent supply of wood waste and we have to keep a bed of coal to insure steam pressure. With 10 tons of coal a day, the cost of coal is about $130 where an equivalent of sawdust and other wood waste costs us only $65. Could you combine these fuels, feeding both coal and sawdust?

Mr. Miller: Combined firing of coal and sawdust can be done and is done on many installations. Usually the two fuels are kept separate until they are fed into the furnace. This can be handled in either of two ways. The wood can be stored and fed into the furnace at controlled rates to meet the steam demand, and when the supply of wood becomes exhausted the unit can be switched quickly to coal. The second system is to feed the wood to the furnace as it becomes available and add coal to meet the steam requirements.

R. A. Blaser (Southwest Lumber Mills): What are the size limitations on wood chips where the air distribution system is used?

Mr. Miller: Any chipped wood or any hogged wood would normally meet the requirements. Most knife hogs will produce some particles that will be 6 to 9 inches long and perhaps 1 inch square. So, as long as these pieces do not represent more than 10 to 15 percent of the total wood, the sizing is considered satisfactory.

Arthur B. Iffland (J. C. Iffland Lumber Co.): We are getting about 3 pounds of steam out of a pound of wood. Would a spreader stoker increase this?

Mr. Miller: Considering the type of wood refuse you have it should be possible to get more than 3 pounds of steam out of a pound of wood. A spreader stoker alone will not be a complete answer for it probably would require improved air-fuel ratio control.

Halsey M. Hicks (Brattleboro, Vermont): Does uniformity in the wood fuel make any difference?

Mr. Miller: Yes, the uniformity in the wood fuel is important. As pointed out to Mr. Blaser, there is quite a range in sizes permitted but as in other fuels, the best operation is obtained when essentially the same size is obtained at all times. By this we mean that for best operation not all of the large particles should be burned for a 15-minute period and then followed by the sawdust. The chips from a portable chipper would make an ideal fuel but very seldom is such wood available.

C. R. Silversides (Abinbi Power & Paper Co., Ltd.): We are installing central heating for a camp of 100 men. The burner will use 500 to 1,000 pounds per hour. We expect to use wood from a portable chipper.

Mr. Miller: Although this unit is somewhat smaller than we normally deal in, I can see no reason why a completely satisfactory system could not be used. With the chips from a portable chipper the fuel feed handling system could be much simplified. This type of wood refuse is much more uniform than that normally expected in hogged fuel and therefore a more uniform flow would be obtained.

E. W. Foss (Cornell University): At Cornell, we have been working on the dehydration of food. Chipped wood as a fuel might be of importance for this process.

Mr. Miller: For drying of lumber I would assume that products of combustion would be mixed directly with the air for drying; however, for the dehydration of food we would expect that a direct fired air heater would be the most advantageous. This system would insure clean air and would pick up none of the products of combustion which might contaminate the food.

Briquets From Sawdust, Bark and Other Waste

WALTER W. LETTS, *Northville, New York*

Fuel From Wood Residues

How many of our American people have ever stopped to consider the real meaning and importance of that commodity which we call fuel? Fuel turns the wheels of our industries to produce the many items essential to our American living. Our deposits of coal and oil are being depleted to meet the ever increasing demand for fuel and large appropriations are expended on research each year to find ways and means to relieve this critical condition.

A partial answer to the problem lies in the use of wood, the oldest fuel known to man. Use of surplus or presently discarded wood alone would supply fuel requirements provided it could be concentrated and distributed economically.

Recently a machine has been perfected that will produce from unused forest materials (using no additive whatever) a very high-grade fuel, three and one-half times the original density of wood, and having a bulk weight approximately 90 percent that of chestnut coal. The product is so firmly knit together that in handling it sheds less dust than most of our solid fuels.

Sawdust Briquets

Since 1930 a form of compressed wood fuel in small log form has been manufactured and sold. Further development of stoker fuel along the same line has taken place. Both require rather elaborate equipment and a volume of sawdust not generally available.

A patented method of producing briquets from sawdust and other wood wastes has been developed by Walter Letts of Northville, New York. This fuel is now being manufactured and sold under the registered name of Letts Burnets. The Burnets consist of small cylinders, 1⅛ inches in diameter, broken into short lengths. Laboratory tests of Burnets indicate an average heat value of 9,000 Btu. per pound, as compared with 12,000 for anthracite and 14,500 for the highest grade of steam coal. These briquets have more than three times the heat value of wood by volume and burn with twice the heat obtained from an equal volume of charcoal. Burnets burn with a hot, blue flame when fully ignited, and under controlled draft will make a hot, low-burning, long-lasting fuel, leaving practically no ash or residue. Burnets are free of dust, clean to handle and are easily ignited.

Equipment Requirements and Availability

Special equipment for making these Burnets is made by The Sandy Hill Iron and Brass Works, Hudson Falls, New York. Two sizes are available, a single head machine having 8 forming tubes and a double head machine having 16 forming tubes. The approximate cost of the 8-tube model is $20,000 while the cost of the double-head machine would run approximately $32,000. In addition to the forming equipment, each installation would require supplementary equipment, such as driers designed for the particular installation. Complete equipment would include two whirlwind variable speed driers, one specially designed disintegrator, one air fan, steam coils, and a low or high pressure steam supply. Power is optional: if a Diesel engine is used the heat from the radiator and exhaust will contribute a large volume of heat required for the whirl-dryers.

Drier

To produce Burnets, waste material must be dry, with moisture contents of 6 to 10 percent. The whirlwind drier was developed to insure fast and safe drying. This drier disposes of all gas laden humidified air and has no hidden pockets.

Process

Wood in the form of forest waste, mill slabs, edgings, or trimmings must be put through a chipper or wood hog, cutting the wood fine enough to be handled by the disintegrator. Material that has a moisture content of more than 25 percent must be passed through a drier before entering the disintegrator, where it is ground to fineness that will pass through a quarter or five-sixteenth screen. It is then put through a variable-speed whirlwind drier, which will assure a steady flow of dry material into the hopper of the Burnet machine.

Production

Production, based on actual operation of an eight tube machine, shows a large variation, depending on type of material used. Thin, fluffy white pine shavings average 650 to 750 pounds of Burnets per hour; white pine sawdust 800 to 900 pounds per hour; hardwood shavings, turnings and dust 850 to 900 pounds per hour; various kinds of pulpwood bark up to 1220 pounds per hour. The increased

yield from bark is due to the different texture of the bark.

One operator can easily supervise a four-unit operation, as his principal duty is to see that each machine receives a steady continuous flow of material.

Use for Wood Residues

The briquetting machine described provides a means of utilizing two major classes of wood residues to provide additional income and eliminate the expense of disposal.

The combined operation of a saw and planing mill develops enough wood residues in manufacturing each thousand board feet of finished lumber to produce approximately one ton of Burnets. The cost of reducing green pine shavings or sawdust to Burnets is estimated at $14 to $16 per ton, bringing Burnets into competition with the local coal supply. For air or kiln dried material, the cost would be substantially reduced. Another class of residue suitable for briquetting is pulpwood bark, if removed by the dry method such as the Sandy Hill Peppy Peeler, which is in use by several of the large paper mills. Bark in small pieces and at a low moisture content, can be economically processed into Burnets. The bark from one cord of pulpwood will produce 350 to 500 pounds of Burnets, having an average heat value of approximately 9,000 Btu's per pound.

Markets

The bag fuel market has reached large tonnage volume and is on the increase. Charcoal is becoming scarce and Burnets are proving a satisfactory substitute for charcoal briquets, for example in railroad dining car grills, and can be sold at very much lower cost. Burnets are proving their worth in this field and find a ready acceptance for they are clean to handle, need no kindling to start them burning, and produce an abundance of clean heat.

Discussion

T. S. Veazey, Jr. (Anaconda Copper Mining Co.): Is the method you mention now in commercial use?

Mr. Letts: One machine is in operation. A second is now under construction and will be in use within a short time. Our present pilot machine has produced carload, truck and customer deliveries and we have several large installations in the process of closing at the present time. The manufacture and sale of this equipment has been taken over by one of our oldest and most complete manufacturing plants of paper making machinery in the country.

R. R. Alexander (Carthage Machine Co.): Could you cut down on the diameter of the cylinders?

Mr. Letts: During the course of developing the Burnet machine, we experimented with several sizes, but found the 1⅛ inch to be the most efficient and to give maximum capacity production of the compression unit.

D. B. Frampton, Jr. (D. B. Frampton & Co.): Will the briquets pick up moisture, and what happens if they get wet?

Mr. Letts: Burnets must be stored in a reasonably dry place and when put up in paper bags they have been kept for over two years without noticeable change. However, if they are allowed to come in contact with extreme moisture or water, they will disintegrate.

Edgar L. Heermance (Northeastern Wood Utilization Council): Just what do you mean by clean burning, and can briquets compete locally with hard coal?

Mr. Letts: If your sawdust supply is waste that you must get rid of, the cost of briquets with an 8-tube unit would probably be less than the local price of anthracite. In a large Burnets unit, requiring very little labor, the cost ought to be about as low as the cost of mining coal. Burnets would be as clean to burn as coal, with no creosote problem such as you are apt to have with stick wood. They could be fed to a domestic furnace by hand or with a mechanical stoker just like coal. The same furnace could be used as for coal, if you keep the drafts tight; not as much air is required. However, the demand for sawdust briquets for other uses has been so great that we have not paid much attention to that type of use. They are primarily a substitute for charcoal, at a very much lower price. One railroad is buying briquets in carload lots for their dining car grills. For apartment or picnic use, a woman can pick up a bag at the store, just as she formerly picked up a bag of charcoal.

A. Koroleff (Pulp & Paper Research Institute of Canada): What about freight rates, if you want to ship in volume?

Mr. Letts: If put up in bags, the rate is about the same as for coal. At the present we are going into the matter of freight rates on Letts Burnets. At the present we are led to believe that this material being fuel of practically the same bulk weight as coal, will take the same rate in comparative shipments.

R. D. Pauley (Weyerhaeuser Timber Co.): Rates on Pres-to-logs are about the same as those for coal and were originally set up to be competitive with coal. This applies to West Coast. I don't know anything about the Eastern tariff.

Characteristics of Wood as Fuel

R. H. P. MILLER, *Engineer, Forest Products Laboratory,*[1] *Forest Service, U. S. Department of Agriculture*

The thermal characteristics and major advantages of wood as a fuel are briefly summarized.

General Information on Fuel Wood

ON A quantity basis, fuel wood continues to be one of the important products taken from the forest. In 1943, for example, it was estimated that a total of about 64,000,000 cords of wood was used as fuel in this country. Fuel wood generally has the lowest value of any product obtained from the forest and, therefore, should not be used for fuel if other markets can be found. Some inferior species and low quality trees, however, have no value for other uses, and, therefore, should be cut and used as fuel in order to improve the timber stands.

Some Advantages and Disadvantages of Fuel Wood

As a fuel, wood has certain distinct advantages. It is clean, burns with little smoke or soot, starts burning easily, gives a quick heat, and has a very low ash content. One cord of the hardwoods produces less than 100 pounds of fine ash, while one ton of hard coal produces about 200 pounds of ash and clinkers. A farmer can produce his supply of fuel wood with practically no additional investment in equipment, and can do the work during his slack season. By cutting fuel wood wisely, the farmer can also improve his wood lot.

One disadvantage of wood as fuel is that it is bulky and heavy in relation to its heat content. For this reason, it is largely used for fuel in the rural districts and small towns where the hauling distance from the woods or mill to the consumer is short. Maintenance of a low fire presents a difficulty when using fuel wood in that the creosote in burning wood condenses out in the flues and chimney. Fuelwood production in terms of heat value requires more man-hours than other fuels, such as coal or oil. This, of course, is largely due to the fact that wood is heavy and bulky for its heat content and because fuel wood does not have so high a concentration of material at the source as the other fuels, and, therefore, does not lend itself to highly mechanized equipment. However, in emergencies, local people can cut and haul their own fuel wood. This is the case because the necessary tools and equipment are generally available, highly skilled labor is not required, and the whole process of producing fuel wood lends itself to small operations.

Composition and Heat Value of Wood

Wood is composed of 50 to 54 percent of cellulose, 15 to 18 percent hemicellulose, 26 to 28 percent lignin, and minor quantities of other constituents. The ultimate analysis of wood is given as about 50 percent carbon, 6 percent hydrogen, 43 percent oxygen, and about 1 percent of ash, nitrogen, etc.

One pound of oven-dried wood substance of any species has a calorific value of about 8,600 Btu. The presence of other substances, such as oils, resins, and extractives, somewhat changes the actual calorific value of different species. Resinous woods, such as pine, have a higher calorific value than nonresinous woods, such as ash.

In burning wood, it is essential to have the wood as dry as possible in order to produce more heat per pound and per dollar of the fuel, to obtain a higher efficiency, and to lessen the creosote problem. Oven-dried red oak wood with a calorific value of 8,600 Btu. will yield about 7,100 Btu. of usable heat with 50 percent excess air and a flue gas temperature of 450° F., while well air-dried wood yields about 5,700 Btu. and green wood about 3,400 Btu. under the same conditions per pound of fuel. If wood is sold on a weight basis, green wood would have about 60 percent of the heat value of well air-dried wood for the majority of native woods. The difference, however, would be greater for woods such as hemlock and aspen that have a very high moisture content in the green condition. Although stove wood is coming to be sold more and more on a weight basis, wood is generally sold on a cord or volume basis (128 cubic feet). On a cord basis, green wood yields about 80 percent of the available heat as compared with the heat produced by the burning of well air-dried wood.

Since air-dried wood has a higher moisture content and a higher volatile content than the average good coal, the combustion of wood is preceded by evaporation of the moisture and distillation and burning of the volatiles before the fixed carbon burns. The evaporation of the moisture absorbs

[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

about 1,000 Btu. per pound of moisture. At temperatures below 500° F., distillation of the volatile matter also absorbs heat. Beyond 540° F., exothermic reaction takes place and the distillation of the volatile matter continues with the evolution of some heat even if no additional air is supplied. In small pieces of wood, such as sawdust, the different phases of burning occur in rapid succession. With large chunks of wood, the processes are overlapping, because wood is a very poor conductor of heat. To get complete combustion of the volatile gases formed, it is necessary to supply about 80 percent of the total air required close to the surface of the fuel bed where it can readily mix with the volatilized gases. Since these gases do not ignite below 1,100° F., it is best to burn dry wood in order to obtain a higher maximum temperature.

Unburned volatiles resulting from incomplete combustion of wood can cause a large loss in efficiency. These gases are also a source of trouble in stoves and furnaces, because of the creosote, tarry substances, and acetic acid they contain. For these reasons the factors necessary for complete combustion are summarized. Sufficient air must be supplied around or over the fuel bed. This air must be mixed with the gases given off by the wood while the gases are still hotter than 1,100° F. and have not come in contact with cooling surfaces. Theoretically, it takes 6 pounds of air to burn 1 pound of oven-dried wood, but actually more air is required because the air and gases are not thoroughly mixed.

Avoidance of Creosote

Creosote and other products of distillation leaking out of the flue joints and at the chimney thimble make the burning of wood very objectionable in domestic heating. In severely cold weather, there is generally less creosote trouble because with a hot fire the gases are kept hotter than 1,100° F. and, if sufficient air is supplied, clean burning takes place and the creosote problem will be avoided. Also, with a hot fire the flue gas temperatures are higher and the creosote and tarry materials that are present are carried out of the chimney in the form of a vapor and are not deposited as a condensate. In order to prevent undue creosote trouble, it is best to burn dry wood in a hot small fire rather than in a large smoldering fire. Refueling the stove at more frequent intervals with smaller amounts of fuel also helps. Short stove pipes and inside chimneys also help to keep the creosote from condensing out.

Improvements in Wood Burning

In the last few years, stoves and furnaces of the hopper type that are designed specifically for wood have been put on the market. The main features of these units are that provision has been made to introduce sufficient secondary air and that flame travel is such that the gases can be burned before they contact heat-absorbing surfaces.

In some cases, wood as a fuel has also been improved. Mill and planer wastes used in the manufacture of certain pressure-formed briquets are dried to about 6 percent moisture content and then pressurized so that the wood plasticizes itself and forms a firm briquet. Wood in this form has a greater density and also a much higher bulk density. Pressure-formed briquets are also made in 1-inch-diameter sizes and broken into short lengths. This type of wood fuel works satisfactorily in domestic coal stokers. Wood in the form of chips also lends itself to automatic feeding, and can be burned very efficiently in large installations.

TECHNICAL SESSION IX—Thu., May 10, 1951, 2:00 P. M.

General Subject: Testing and Evaluation of Forest Products

Co-Sponsor: American Society for Testing Materials, Committee D–7 on Wood

Chairman: L. J. Markwardt—**Recorder:** J. S. Bethel

Tests and Properties of Tropical Woods[1]

FREDERICK F. WANGAARD, *Yale School of Forestry*

Mechanical properties, density, shrinkage, decay resistance, and a number of other characteristics of 48 tropical woods have been obtained and compared with corresponding attributes of domestic woods. A hypothesis of low fiber saturation point is suggested as a possible explanation for some differences. Species profiles related to use requirements are shown.

Introduction

RECENT years have witnessed a growing interest in the commercial possibilities of many tropical woods for structural and industrial uses. Such interest is based on the recognition of tropical forests as comprising the largest and most diversified stands of timber in the world. There are less than 1000 tree species native to the United States and only about 90 of these attain such size and quality as to be considered commercially important. In contrast to the relatively limited number of domestic woods, it is conservatively estimated that the forests of Central and South America alone include over 10,000 tree species.

Most studies of tropical woods have been directed primarily toward providing a sound technical basis for the proper utilization of particular species, a number of which have shown superior qualities for a variety of special purposes. In addition to such research in the field of application, the great diversity of tropical woods affords an excellent opportunity to increase our basic knowledge concerning the relationships of structure, density, and moisture content to the properties of wood.

It is the purpose of this paper (1) to indicate how tests of tropical woods are contributing to fundamental knowledge of wood behavior and (2) to outline methods used in the evaluation of tropical woods with respect to their potential utilization. Both phases have implications of interest to the wood technologist or timber engineer apart from their specific concern with tropical woods.

The data on which this paper is based were collected in the course of a continuing study which has been conducted at the Yale School of Forestry since 1947 under the sponsorship of the Navy Department through the Office of Naval Research and Bureau of Ships. The scope of the over-all study includes determination of mechanical properties, density, shrinkage, decay resistance, rate of moisture absorption, resistance to weathering, and the characteristics of the wood in relation to seasoning, paint holding, machining, gluing, and steam bending. Through arrangement with the William F. Clapp Laboratories at Duxbury, Mass. certain of these woods are subjected to exposure in infested waters to determine their resistance to marine-borer attack. Other tests are conducted at the New York Naval Shipyard to determine resistance to fire and abrasion, and at the Institute of Paper Chemistry, Appleton, Wis., to determine chemical composition of selected woods.

Two comprehensive reports have been issued covering mechanical properties of unseasoned timber together with such physical properties as specific gravity, shrinkage, decay resistance, and air-seasoning characteristics of 48 tropical American timbers (*3, 4*). Progress on other phases of the work has been described in an additional series of technical reports (*1, 2, 7*), and studies are continuing on these phases as well as on the determination of mechanical properties of seasoned wood.

Contributions to Fundamental Knowledge of Wood

Tropical woods present not only a greater number of species for investigation than do our domestic woods but they also display a greater diversity. Where, for example, among the species of the temperate zones can be found woods so unlike in their characteristics as balsa and lignum vitae? The relatively limited group of 48 species for which significant data have been gathered in the present study does not, of course, represent the entire range of specific gravity shown by tropical woods, but it does afford a sampling of density classes for which only few data are available from domestic sources.

Fig. 1 shows, by means of two frequency diagrams, the proportionate distribution among specific gravity classes of 48 tropical woods studied at Yale and 168 domestic woods tested at the Forest Products Laboratory (*5*). The bulk of domestic woods are found in the 0.30 to 0.60 specific gravity classes and only a small proportion of them occur in specific gravity classes of 0.70 or greater. Of the tropical woods studied thus far a sizeable representation is shown for specific gravity classes from 0.40 to 0.80 and further studies will undoubtedly extend

[1] A report on current research at Yale which is sponsored by the Office of Naval Research, U. S. Navy Department, under Contract N6–ori–44, Task Order XV (Project Designation No. NR–033–020).

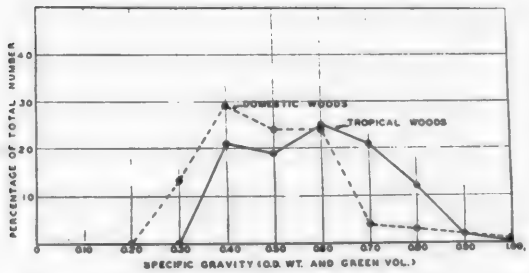

Fig. 1.—Frequency diagram showing specific gravity distribution for 168 domestic and 48 tropical woods. (Data on domestic woods from the Forest Products Laboratory.)

this range. Limiting attention to presently available data, however, it is evident that a considerable addition has already been made to the species representation toward the upper end of the specific gravity range, specifically from 0.60 to 0.90. A substantial basis for comparison of tropical and domestic woods in the specific gravity range of 0.40 to 0.60 is also provided.

Strength-Specific Gravity Relationships

The relationships between various strength properties and specific gravity have been determined by the Forest Products Laboratory on the basis of tests of the domestic woods represented in Fig. 1. Comparison of results obtained from domestic and tropical species in two of these properties is given in the following paragraphs.

According to the Forest Products Laboratory the relationship between modulus of rupture of unseasoned wood and specific gravity is given by the equation $R = 17600\ G^{1.25}$ in which G = specific gravity on an oven-dry weight and green volume

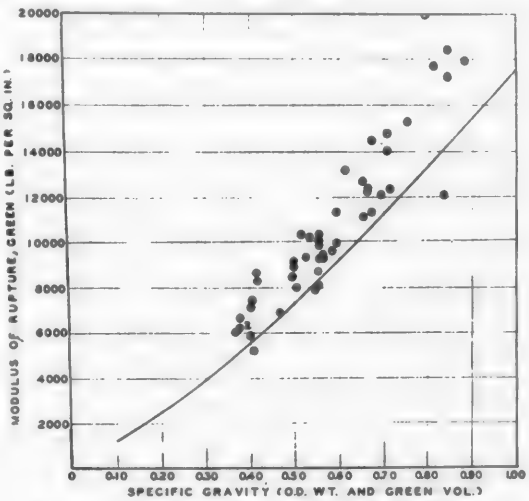

Fig. 2.—Relationship between modulus of rupture (green) and specific gravity. Plotted points: Tropical woods. Curve: F. P. L. curve based on domestic woods.

basis (*5*). The curve shown in Fig. 2 represents this relationship. Data for individual tropical woods are shown as plotted points in Fig. 2. It is evident that a curve drawn through the averages of the plotted points would lie considerably above the Forest Products Laboratory curve, as much as 25 percent toward the upper limits of specific gravity, and that the curves would converge toward the lower specific gravities.

The higher position occupied by tropical woods is confirmed by the data in Fig. 3 which show a similar trend in the relationship between modulus of elasticity of unseasoned wood and specific gravity. The curve in Fig. 3 is the graphic representation of

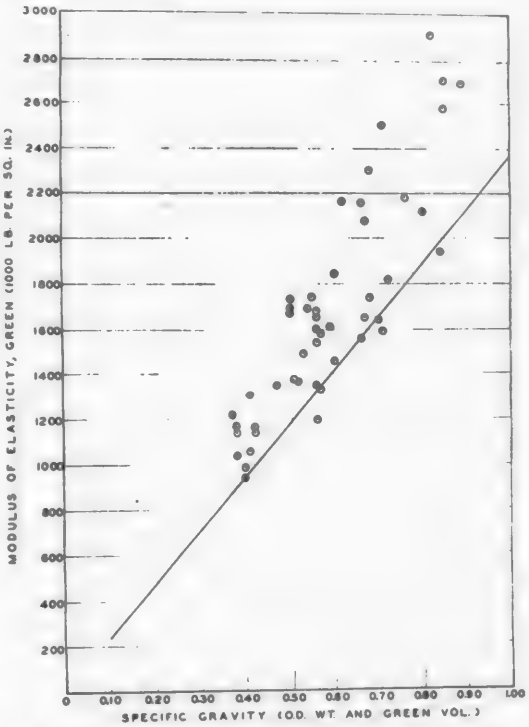

Fig. 3.—Relationship between modulus of elasticity (green) and specific gravity. Plotted points: Tropical woods. Curve: F. P. L. curve based on domestic woods.

the equation $E = 2{,}360{,}000\ G$ which was derived by the Forest Products Laboratory from tests of domestic woods (*5*). Averages of the plotted points representing individual species of tropical woods exceed the Forest Products Laboratory curve by about 30 percent at the upper limits of specific gravity and show a converging trend approaching that curve at lower specific gravities.

In both modulus of rupture and modulus of elasticity these tropical woods generally exceed values anticipated for unseasoned wood on the basis of tests of domestic species. The apparent superiority of the tropical woods is particularly notable at the

higher specific gravities for which the adequacy of representation afforded by domestic woods might be open to some question.

Shrinkage-Specific Gravity Relationship

A linear relationship between volumetric shrinkage and specific gravity has also been derived by the Forest Products Laboratory from tests of domestic woods (*6*). The curve of the equation denoting this relationship (volumetric shrinkage = 28.0 G) is shown in Fig. 4 together with plotted points based

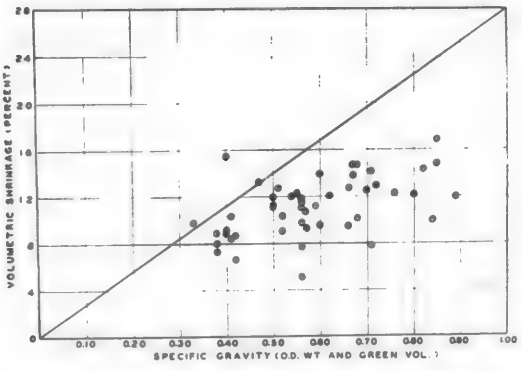

Fig. 4.—Relationship between volumetric shrinkage and specific gravity. Plotted points: Tropical woods. Curve: F. P. L. curve based on domestic woods.

on measurements of shrinkage from the green to oven-dry condition of individual species of tropical origin.

As in the case of the strength properties previously discussed, the plotted data for tropical woods deviate markedly from the regression line based on tests of domestic woods. At the higher specific gravities, average shrinkage values for the tropical woods are only approximately 3/5 as great as those indicated by the curve. The trend line shown by the data for tropical woods is considerably less steep than the Forest Products Laboratory curve and converges with the latter curve at lower specific gravities.

Appraisal of the Differences

Apart from the practical interest that is naturally attached to tropical woods from the standpoint of their greater strength and stiffness (in the green condition), associated with reduced shrinkage in comparison with the properties shown by typical domestic woods of like density, the foregoing data suggest some questions of fundamental interest.

It is recognized that presently available data on domestic woods are not heavily represented in the specific gravity classes above 0.60. Is it not possible, therefore, that these long accepted relationships with specific gravity can be improved for wood in general, particularly in the higher specific gravity range, by the inclusion of data derived from tropical woods?

Or is it likely that a fundamental difference exists between temperate and tropical woods as a consequence of their contrasting conditions of growth? At the present stage of investigation when the early accumulation of considerably more data on tropical woods is anticipated, it would be premature to attempt to answer these questions conclusively.

One hypothesis that appears to explain the results of both strength and shrinkage tests is that the tropical woods for which data are presented here may be characterized by a lower fiber saturation point than the majority of domestic woods. A saturated cell wall containing less moisture per unit of wood substance would explain both the higher strength and stiffness exhibited by these woods as well as their lesser shrinkage from the green to oven-dry condition. Other factors may account for the extremely low shrinkage values shown by certain tropical woods but it is difficult to see how such factors could simultaneously affect strength and stiffness so favorably.

Ratios of air-dry and green strength properties are so far limited to a relatively small number of tropical woods. Available data, however, tend to substantiate the hypothesis concerning a lower fiber saturation point for the woods tested. Table 1 shows

TABLE 1.—COMPARATIVE EFFECT OF AIR DRYING UPON STRENGTH PROPERTIES OF TROPICAL AND DOMESTIC HARDWOODS

Property	Ratio of air-dry strength to green strength	
	Tropical hardwoods	Domestic hardwoods[1]
Modulus of rupture	1.42	1.59
Modulus of elasticity	1.19	1.31
Maximum crushing strength	1.49	1.95
Side hardness	1.18	1.33
Tension perpendicular to grain	0.97	1.20

[1] Data on domestic hardwoods from U. S. Dept. Agr. Tech. Bul. 479.

ratios of air-dry to green strength properties for a group of 20 tropical hardwoods studied at Yale and corresponding ratios for a large number of domestic hardwoods from data of the Forest Products Laboratory (*5*). In every property the ratio shown by domestic woods is greater than that of the tropical species. In accordance with the hypothesis offered in the preceding paragraph, the greater improvement of domestic woods in drying to 12 percent moisture content may be explained by the larger proportion of cell wall moisture lost by these woods. Analysis of these preliminary data on ratios of dry to green strengths for tropical woods fails to show any consistent relationship with specific gravity which suggests that tropical woods of all density classes share the characteristic of low fiber saturation point. Further studies involving direct determination of fiber saturation point will be necessary to confirm this hypothesis.

Incidentally, it is of interest to point out, as shown in Table 1, an actual reduction in average tensile strength perpendicular to the grain of a number of tropical woods as a consequence of air

drying. While it is, of course, possible that inadvertant minute checking (although painstakingly avoided in the treatment and selection of test material) may have contributed to this result, other factors including increased stiffness across the grain and consequent stress concentrations probably are involved.

Evaluation of Tropical Woods for Specific Uses

The principal objective of the study on which this paper is based is to develop a general use classification for tropical woods. Such a classification involves an evaluation of each species studied with respect to the uses for which the wood appears to be adapted on the basis of its properties. It is difficult, if not impossible, to specify precisely what types of test are essential to the development of a complete use classification. Selection of tests is obviously related to the objectives of the study. However, the tests that were previously enumerated in describing the scope of the over-all tropical wood research program at Yale appear to be reasonably well adapted to a limited general classification at least.

On the basis of these tests, supplemented by the results of decades of trial and error "research" by non-technical users of these woods in the tropics, a classification consisting of the following items has been developed: Agricultural implements and vehicles, boatbuilding (decking, planking, framing, keels and under-water structural members), construction timbers, cross ties, exterior use, flooring, tropical frame construction, furniture and cabinet work, instruments, marine piling and construction, millwork, patterns, sporting and athletic goods, tool handles, veneer and plywood (utility and decorative).

For each of these uses a particular combination of qualities is essential, or at least favorable. Some of the categories are too broad to permit of evaluation by a single set of properties. Furniture and cabinet work, for example, must be broken down into such subdivisions as solid wood parts (figured or plain), turnings, figured or plain face veneers, crossbands and core stock, and molded or bent-wood members. An analysis of the service conditions involved in any particular use will permit an enumeration of desired qualities.

However, even after selection has been made of a particular set of properties pertinent to a specific use, it is unlikely that absolute numerical measures of quality in any particular category can be established. What, for example, is the minimum value of hardness permitted in flooring, or precisely what degree of decay resistance is essential to a satisfactory boat decking? Or how much shrinkage is permissible in pattern stock?

Since the answers to these and numerous similar questions are seldom known, evaluation of a wood under investigation is commonly based upon comparison with a wood of known suitability for the particular use. It is important, of course, that the comparison include insofar as possible the essential characteristics related to this use but just as important is the exclusion from comparison of properties that are not pertinent to the case.

A few examples will serve to illustrate what has been designated as the "species profile" method of species evaluation.

Ship and Boat Decking

Among the more important properties of a decking wood are low shrinkage, low moisture absorption, moderate weight, a high degree of resistance to warp, weathering, and decay, and adequate hardness and compressive strength across the grain. Burma teak is recognized as meeting these requirements to a high degree. Insofar as possible, 12 selected species are compared directly with teak in Fig. 5, A–F. The data upon which these comparisons are based have been taken from various published reports (*1, 2, 3, 4*). The strength properties given represent unseasoned wood inasmuch as tests of air-dry wood are still incomplete. The profile scales are so arranged that deficiencies from the standard of quality exhibited by teak are revealed by a lower position on the graph.

Albizzia caribaea and *Bagassa guianensis* (Fig. 5A) are notably inferior to teak (*Tectona grandis*) in shrinkage and specific gravity, and *B. guianensis* is also inferior in weathering resistance. In other essential characteristics both appear to be nearly equivalent or superior to teak. *Buchenavia capitata* is shown to be closely comparable to teak and, with the exception of specific gravity, *Chlorophora tinctoria* appears to compare favorably (Fig. 5B). *Cordia alliodora* (Fig. 5C) has the advantage of being lower in density than teak but is deficient in tangential shrinkage, moisture absorption, hardness, and compressive strength. In the same figure *Dicorynia paraensis* parallels teak at a slightly lower level except for a notable deficiency in tangential shrinkage. *Nectandra concinna* closely approaches teak in nearly all categories of comparison, whereas *Hymenaea courbaril* is generally low in all properties except decay resistance, hardness, and compressive strength (Fig. 5D). *Pseudosamanea guachapele* closely approximates teak throughout and *Tabebuia pentaphylla* also approaches teak in all categories except moisture absorption in which it is notably deficient (Fig. 5E). *Vitex Cooperi* is deficient in tangential shrinkage but otherwise compares favorably with teak, whereas *Terminalia amazonia* is deficient in shrinkage, specific gravity, and weathering resistance (Fig. 5F). Of the woods shown in Fig. 5, greatest promise of successful application is indicated for *Buchenavia capitata, Nectandra concinna,* and *Chlorophora tinctoria.*

Patterns

Pattern making imposes rigid requirements upon the selection of suitable woods. Among the requisite properties are low shrinkage, a high degree of

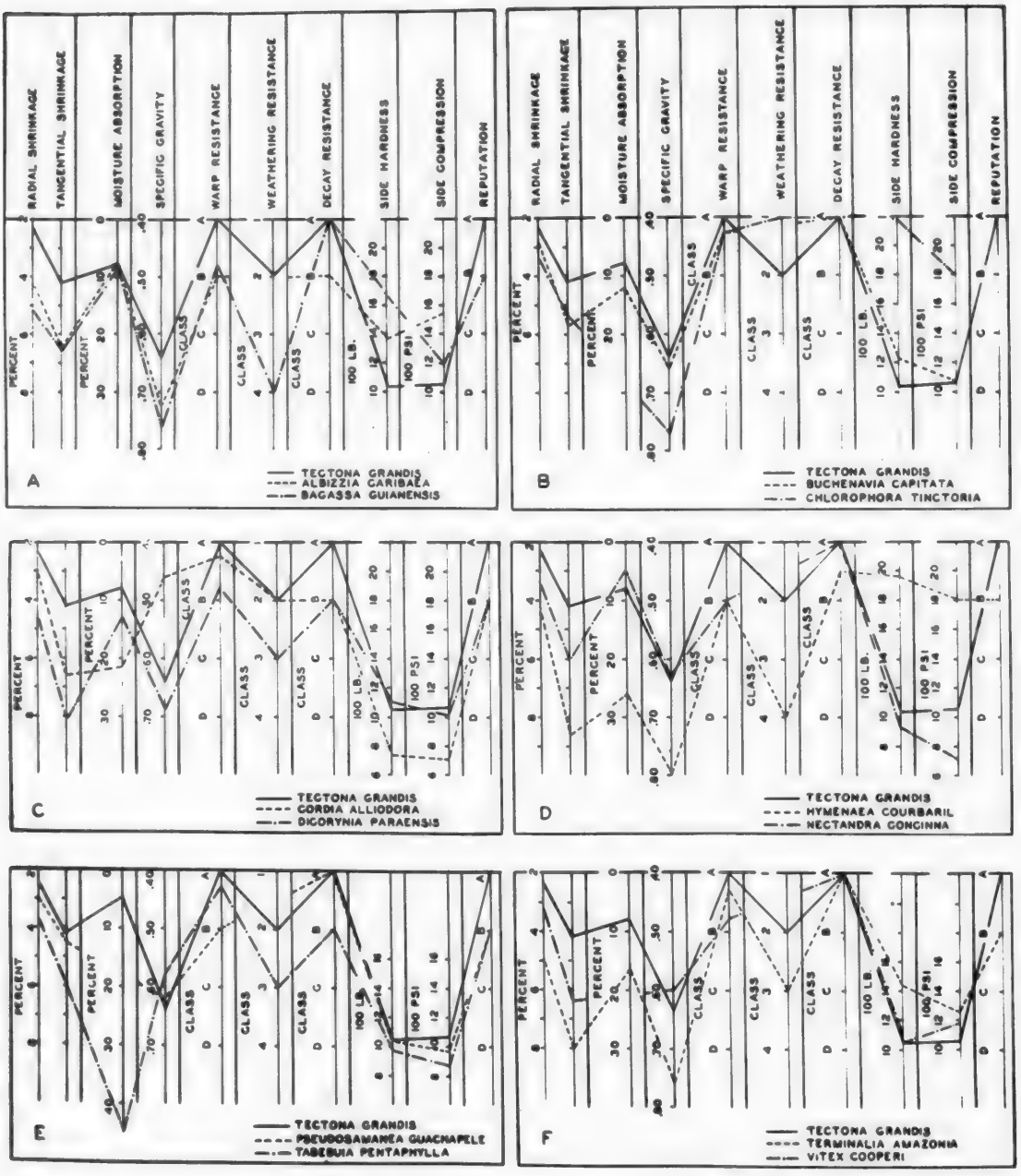

Fig. 5.—Species profiles of 12 tropical woods compared with that of teak (*Tectona grandis*) in evaluating suitability for ship and boat decking.

warp resistance, light weight, uniformity of texture, ease of gluing, a moderate degree of softness, good workability, and retention of surface smoothness with change in moisture content. Mahogany and slow-growth, even-textured eastern white pine (cork pine) are among the few woods that have successfully met service requirements for such use.

Profiles for six tropical woods based on data appearing in a number of reports (*2, 3, 4, 7*) are compared with that of mahogany (*Swietenia macrophylla*) in Fig. 6 (A–C). As noted previously, strength properties are those of unseasoned wood. Although mahogany was selected for comparative purposes, it is perhaps misleading to compare the

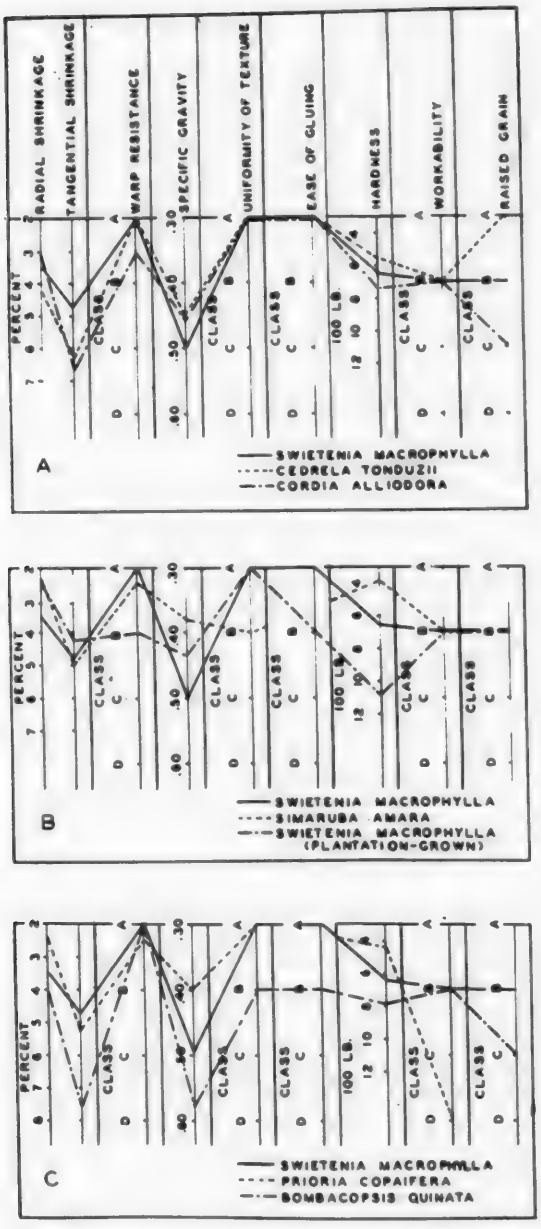

Fig. 6.—Species profiles of six tropical woods compared with that of mahogany (*Swietenia macrophylla*) in evaluating suitability for patterns.

shrinkage of these tropical species with mahogany alone. Eastern white pine, for example, is characterized by a tangential shrinkage of nearly 6 percent which gives some idea of an acceptable tolerance in dimensional stability.

With the possible exception of tangential shrinkage, *Cedrela Tonduzii* compares favorably with mahogany in all essential characteristics (Fig. 6A). *Cordia alliodora* is shown in the same figure to have an additional deficiency from the standpoint of raised grain. *Simaruba amara* is shown to be equivalent or superior to mahogany, being lower in weight, somewhat softer, and only slightly less uniform in texture, whereas young plantation-grown mahogany is deficient to forest-grown mahogany in specific gravity and hardness (Fig. 6B). Both *Prioria Copaifera* and *Bombacopsis quinata* appear to have serious deficiencies, the former chiefly in its poor workability and *Bombacopsis quinata* as a consequence of its excessive tangential shrinkage and density together with a tendency toward raised grain (Fig. 6C).

Impact Tool Handles

High shock resistance, toughness, bending strength, moderate weight, freedom from warp, moderate shrinkage, and machinability are among the more important characteristics desired in wood handles for impact tools. Hickory is generally recognized as a domestic wood possessing suitable qualities for such use. On the basis of available data (*3, 4*), six tropical woods are compared with hickory in Fig. 7 (A–C).

In Fig. 7A *Chlorophora tinctoria* is shown to be nearly equal or superior to hickory in all respects except work to maximum load in static bending which provides a measure of shock resistance. *Apuleia molaris* shares this deficiency in shock resistance and is somewhat heavier than hickory, but shows a definite superiority to hickory in all other respects.

As shown in Fig. 7B *Eschweilera Sagotiana* is much heavier than hickory and yet fails to equal hickory in shock resistance. In other essential characteristics it closely parallels hickory. *Pouteria carabobensis* is generally equal to hickory in all but shock resistance, which is deficient, and bending strength which greatly exceeds that of hickory.

Pterocarpus vernalis (Fig. 7C) is considerably lighter in weight and possesses less than half the shock resistance of hickory but appears superior in other respects. In the same figure *Tabebuia heterotricha,* although appreciably heavier, is markedly superior to hickory in all other respects except machinability. This superiority is especially notable with respect to bending strength and elastic resilience (work to proportional limit). Most unusual perhaps is the favorable comparison with hickory shown by *Tabebuia heterotricha* in shock resistance as measured by work to maximum load. Few woods are known to exceed hickory in this property.

Summary

The testing of tropical woods serves a two-fold purpose. Because of their wide range in density and diversity of structure, these woods afford an opportunity to broaden basic knowledge of wood behavior. As stated in the first section of this paper, a number of departures from specific gravity and moisture content relationships anticipated on the

basis of tests of domestic woods are indicated. It is suggested that a part of the observed difference may be due to a lower fiber saturation point in most of the tropical woods tested, but proof of this hypothesis awaits further testing.

The more immediate purpose for conducting tropical woods tests is to obtain information relative to the properties of these woods to permit their evaluation for specific use. A "species profile" method of presenting a visual comparison of any wood under consideration with a wood of known adaptability to a particular use is suggested and illustrated with several examples. Application of this method is, of course, not limited to tropical woods but may be employed to advantage in the evaluation of any wood for new uses.

Acknowledgments

The writer acknowledges the assistance of Rowland M. Garratt who prepared a number of the figures for this paper.

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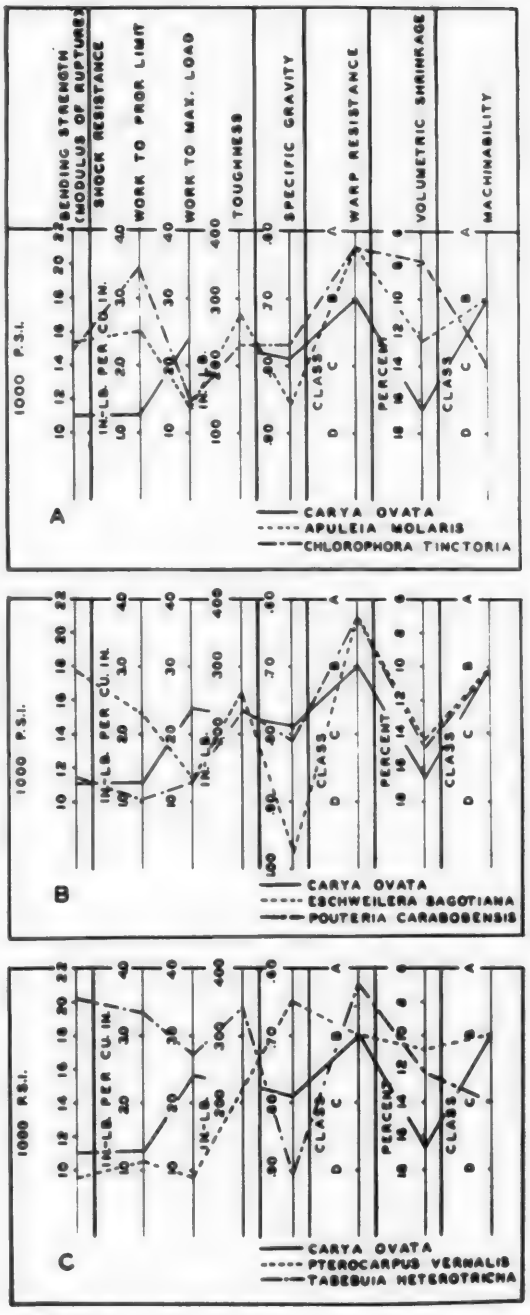

Fig. 7.—Species profiles of six tropical woods compared with that of hickory (*Carya ovata*) in evaluating suitability for impact tool handles.

Discussion

R. C. Rietz—Comments by A. J. Stamm and J. T. Drow (Forest Products Laboratory): Mr. Wangaard states "One hypothesis that appears to explain the results of both strength and shrinkage tests is that the tropical woods for which data are presented here may be characterized by a lower fiber-saturation point than the majority of domestic woods. A saturated cell wall containing less moisture per unit of wood substance would explain both the higher strength and stiffness exhibited by these woods as well as their lesser shrinkage from the green to oven-dry condition."

By definition, the fiber-saturation point is the theoretical state in which the cell walls are fully saturated, and the cell cavities are entirely free of moisture. Such a condition, of course, will never actually be achieved throughout a piece of wood, but for practical purposes it has been shown that the removal of moisture from initially green wood has a negligible effect on the strength properties and on shrinkage so long as the cell walls remain fully saturated. As soon as the moisture content is decreased to the point where the cell walls are no longer fully saturated, a change in strength properties—usually an increase—begins to take place, and the wood starts to shrink.

We do not believe any observed increase in the strength of green tropical woods over domestic species having comparable densities can be attributed to a lower fiber-saturation point or less initial dispersion of the wood substance, especially since, up to the present time, no appreciable variation in fiber-saturation point has been detected among domestic species.

On the other hand, the cell walls are apparently not particular whether they are saturated by water or by other substances such as extractives. It is known that a variety of water-soluble extractives may infiltrate into the fiber structure of wood long after the cells have been formed in the living portion of the tree, and woods containing large amounts of water-soluble extractives invariably have low apparent fiber-saturation points, as determined by the shrinkage from green to the oven-dry condition.

Woods low in water-soluble extractives, and not readily subject to collapse on drying in small sizes and under relatively stress-free conditions approximate the relation

$$S = 0.28\,\delta$$

where S is the shrinkage from green to the oven-dry condition and δ is the specific gravity based on green volume and weight when oven dry.

The constant 0.28 represents the fiber-saturation point on the basis of volume of adsorbed water per unit weight of dry wood. Correcting for the compression of the water, the fiber-saturation point on the basis of the normal weight of water per unit weight of wood is obtained, namely 0.30 to 0.31.

When wood contains large amounts of water-soluble extractives, the constant in the above shrinkage-specific gravity relation is materially decreased. For example, we have tested specimens of redwood with values of the constant as low as 0.18. This corresponds to an apparent fiber-saturation point of 0.20.

The reason for this is that part of the swollen cell wall volume normally occupied by water is occupied by extractives that have infiltrated into the fiber structure, thereby displacing water. When such wood is dried, the final volume of the fiber is bulked by an amount equal to the volume of the extractive remaining in the cell wall. This is the principle by which the swelling and shrinking of wood is reduced by resin treatments and by acetylation. If the extractives are leached out of the wood before drying, the shrinkage is increased. In the case of redwood, for example, the constant in the equation given above becomes practically normal, about 0.27. Extracted redwood thus has a fiber saturation point comparable to that of species which are low in water-soluble extractives, whereas unextracted redwood has a much lower apparent fiber saturation point.

We believe that differences in the observed shrinkage-specific gravity relations of tropical and domestic woods as discussed by Mr. Wangaard on the basis of his figure 4 could possibly be explained on the basis of differences in extractive content. It seems probable that species showing the greatest deviations would be those having the greatest extractive content.

Mr. Wangaard's finding that the strength increase on drying of tropical woods is less than for our native woods is likewise explainable on the basis of extractive content. When woods high in water-soluble extractives are reduced to 12 percent moisture content, they will remain bulked more than extractive-free wood by the amount of the extractives present, hence the increase or decrease in strength over the condition where the fibers are fully saturated will be relatively less.

It must be borne in mind that a low apparent fiber-saturation point of woods having large amounts of water-soluble extractives does not mean a lesser amount of swelling of the wood in the fully swollen condition, but only a smaller amount of moisture by the volume occupied by the extractives. It is not the moisture content in wood but, rather, the relative degree of dispersion of the components of the cellular structure that determines the extent of molecular cross-bonding and, consequently, the strength of the green wood.

It has been demonstrated that any solution that swells wood, for example, alcohol will produce a reduction in strength in proportion to the relative degree of swelling. As a consequence, there is no reason to believe that the presence of water-soluble extractives will have any noteworthy effect on the strength of green wood as compared to wood

swollen by water alone. Other ways of accounting for differences in the strength-specific gravity relations of foreign and domestic woods should hence be sought.

A. J. STAMM
J. T. DROW

Richard N. Hammond (Weyerhaeuser Timber Co.): Has there been any study of moisture content equilibrium?

Mr. Wangaard: That is something we are studying. One of our doctorate students recently began an investigation into the equilibrium moisture content relationships for a number of these woods. His plan is to study both equilibrium moisture content and volumetric changes of wood throughout the range of moisture content below the fibre-saturation point. His study involves specimens from which various extractives have been removed as well as untreated material.

Dean B. Richards (Lilly Company): What was the basis for selecting the woods studied?

Mr. Wangaard; These species were selected for particular uses on the basis of empirical information. However, the basis was not necessarily the strength properties or shrinkage values. Some were selected because of their attractive appearance, others because of favorable reputations for decay resistance, weathering qualities, shock resistance, etc. On the basis of other available data, I believe that the relationships shown are reasonably representative of tropical woods generally.

John Reno (Pacific Lumber Co.): Is the figure of 20 percent for fibre-saturation for redwood, mentioned in the Forest Products Laboratory comments, to be considered satisfactory for present use?

Mr. Wangaard: I am in general agreement with those comments except that I question the statement that fibre-saturation point is not the answer. To say that the strength and shrinkage relationships involved here are due to extractives is not contradictory to the conclusions drawn in the paper, inasmuch as the extractive content of the cell walls and fibre-saturation point are interrelated. However, fibre-saturation point may also be influenced by other factors still unknown.

Some Comparative Characteristics of Second-Growth and Old-Growth Redwood

BENSON H. PAUL, *Chief, Division of Silvicultural Relations, Forest Products Laboratory,*[1] *Forest Service, U. S. Department of Agriculture*

Comparisons were made between old-growth and second-growth redwood with respect to specific gravity, strength, shrinkage, and other significant properties. Silvicultural practices are recommended to produce high-quality timber on the shorter rotations.

Introduction

LUMBER from second growth of western species is now appearing on the market as a result of new methods of logging and sawmilling that utilize relatively young and small-sized trees. Tractor-truck logging and portable sawmills are now operating in young stands that could not be handled profitably by the heavy equipment and large mills designed for old-growth timber.

As more and more second-growth timber comes on the market, it is natural for the merchandiser and user to ask how the new-crop timber compares with that from old-growth trees of the same species. Some comparative characteristics of second-growth and old-growth redwood are presented herewith.

Some time ago the Forest Products Laboratory conducted a rather extensive survey of the variability of old-growth and second-growth redwood (*Sequoia sempervirens*) based on the specific gravity (density) of the wood.[2, 3] Trees growing on soils of different site quality were sampled in both old-growth and second-growth stands. Following the preliminary sampling, standard strength tests were made on representative material from the same localities where specific gravity samples had been obtained. This kind of sampling and testing gave a very reliable picture of the strength properties and characteristics of redwood on a broader basis than had been done before for most native woods.

Width of Growth Rings

Redwood varied widely in width of growth rings, depending upon the kind of stand, whether old growth or second growth, and the chance for development of individual trees, particularly in the second-growth stands.

Most old-growth redwood trees had grown slowly in diameter, many of them from their earliest years. Only 8 percent of the old-growth specific gravity specimens had fewer than 10 rings per inch; 20 to 50 rings per inch were rather common, while again 8 percent of the samples had 60 or more rings to the radial inch. In the closely grown second-growth, ring width varied mostly between 2 and 20 rings per inch with as many as 30 rings per inch in a few samples. Only one of the samples of open-grown second-growth redwood had more than 5 rings per inch (Fig. 1).

Specific Gravity

More than 4,000 specific gravity determinations were made on wood from 56 old-growth redwood trees representing Site Qualities I, II, III, and IV,

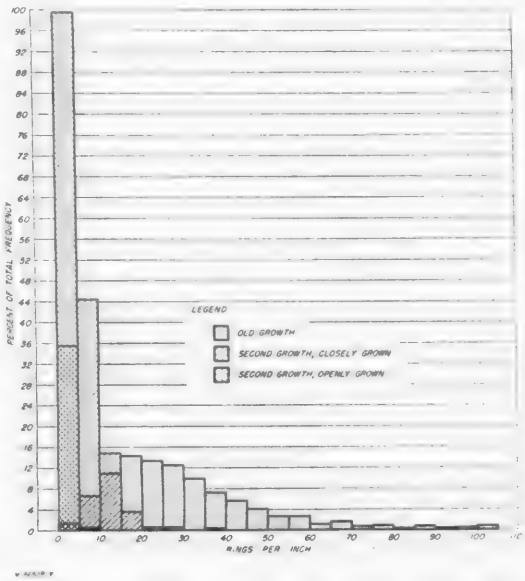

Fig. 1.—Frequency of ring width classes among specimens of old-growth and closely grown or openly grown second-growth redwood.

[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2] Luxford, R. F., and Paul, B. H. Specific Gravity Survey of Redwood. U. S. Forest Products Laboratory Office Report. 1928.

[3] Luxford, R. F., and Markwardt, L. J. The Strength and Related Properties of Redwood. U. S. Dept. of Agr. Test Bull. No. 305. July 1932.

and 987 more specific gravity determinations were made from 42 second-growth trees representing Sites II, III, and IV. The samples from the second-growth trees represented both fully stocked and understocked (openly grown) stands (Fig. 2).

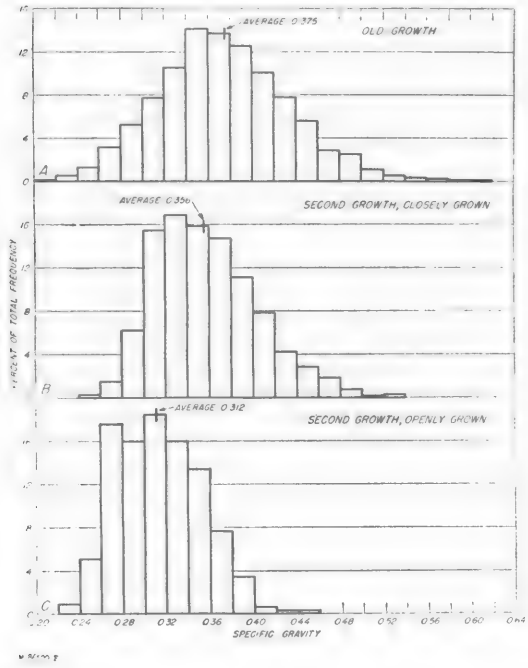

Fig. 2.—Specific gravity range and distribution of specific gravity classes in: A, old-growth; B, closely grown second-growth; and C, openly grown second-growth redwood.

The specific gravity variation in old-growth trees extended over a wide range, with the minimum being 0.21, the maximum 0.62, and the average 0.38. There was considerable variation in different parts of trees and between different trees in the same stand. Average differences in the wood from stands representing different site qualities appeared to be relatively unimportant. In most old-growth trees the lightest material was comprised of wood of exceedingly slow growth in which as many as 100 growth rings were found in a radial inch. Much of the heavier wood represented a medium ring width of 20 to 40 rings per inch, except in the case of compression wood, which frequently contained fewer rings.

Specific gravity of second-growth redwood varied over a shorter range than that of the old-growth. Closely grown second-growth trees averaged 0.36, with a minimum of 0.25 and a maximum of 0.52. The openly grown second-growth trees averaged 0.31, with a range of 0.23 to 0.44. In contrast with old-growth trees, the lightest wood in the second-growth consisted of the very wide-ringed material near the center of the openly grown trees. In the closely grown second-growth trees, as the rings became narrower from the center of the trees outward, there was a general increase in specific gravity. The openly grown trees had for the most part continued to grow rapidly in diameter, with five rings or less per radial inch, and sometimes the rings near the center of the trees equalled 1 inch in width. In the closely grown second-growth trees, initial growth was as few as two rings per inch, with subsequent rings gradually becoming narrower to more than 20 rings per inch for trees from the more closely crowded parts of the stands. This more narrow-ringed wood in the outer parts of these trees was similar in appearance and density to that of equal ring width in old-growth trees; however, this slower-growth zone was relatively thin, which made it difficult to produce boards of uniform ring width and specific gravity from trees having such variable growth. Magnified comparisons of structural appearances of the wood of the three types of growth, representing 24 rings per inch in old-growth, 12 rings per inch in closely grown second-growth, and 3.5 rings per inch in openly grown second-growth trees, are shown in Fig. 3.

Moisture Content

The moisture content of old-growth redwood varied considerably in different parts of the green trees. In the heartwood near the stump of the trees, the moisture equalled an average of 150 percent of the oven-dry weight of the wood and decreased gradually upward in the trees to about 60 percent at 80 feet above the ground, and was only slightly less at greater heights in the tree.[3] On the same basis, the moisture content of the sapwood averaged between 220 and 230 percent from the stump to 80 feet and increased somewhat at greater heights. The greatest average moisture content in sapwood—250 percent of the oven-dry weight of the wood—was found at a height of 175 feet.

In heartwood of second-growth redwood, the moisture content varied from 150 percent at the stump to 60 percent at a height of 60 feet. In the sapwood, a maximum of 185 percent moisture occurred at 14 feet above the ground, and this gradually decreased to 165 percent at 60 feet.

Lumber from second-growth trees having smaller diameters and generally wider sapwood zones contains proportionately more sapwood than that from old-growth trees.

Extractives

Redwood heartwood gains its characteristic color from the presence of materials that infiltrate the cellular structure of the wood when it changes from sapwood to heartwood. A portion of this material is soluble in cold water, more is dissolved by hot water, and somewhat greater amounts by use of alcohol or other chemical solvents. In the extractions made, extractive contents varying from 5 to 28 percent and averaging 10 to 15 percent of the oven-

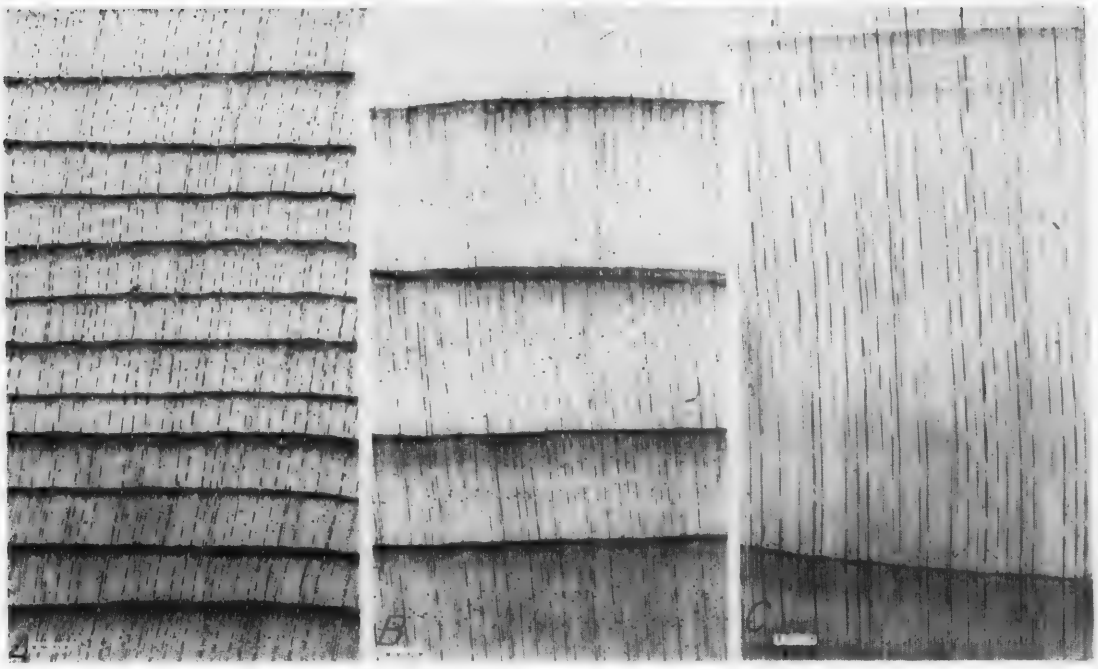

Fig. 3.—Typical wood structure of redwood. A, old growth, 24 rings per inch; B, closely grown second growth, 12 rings per inch; C, openly grown second growth, 3.5 rings per inch. Compare proportional amounts of springwood (light-colored zones) and summerwood (darker zones of growth rings) in the three views.

dry weight of the wood were found in different parts of heartwood of old-growth trees.[4] The sapwood of old-growth trees contained from 4 to 8 percent extractives. In second-growth trees the amount of extractives varied from only 10 to 15 percent in the heartwood and from 3 to 6 percent in the sapwood.

Extractives may influence certain properties of wood such as shrinkage and compressive strength. In some cases shock resistance appeared to be decreased by the presence of extractives. Under some conditions in use extractives of redwood lumber may dissolve and cause discoloration of painted surfaces.

Strength

The variations of strength and related properties of redwood with specific gravity follow the same general trends as have been observed in other species. For example, the heavier wood is stronger and harder. The relationship of specific gravity to bending strength (modulus of rupture) for the three groups of redwood trees is shown in Fig. 4.[5] In old-growth trees tested in a green condition, the bending strength, as measured by the modulus of rupture, varied from 3,100 to 10,800 pounds per square

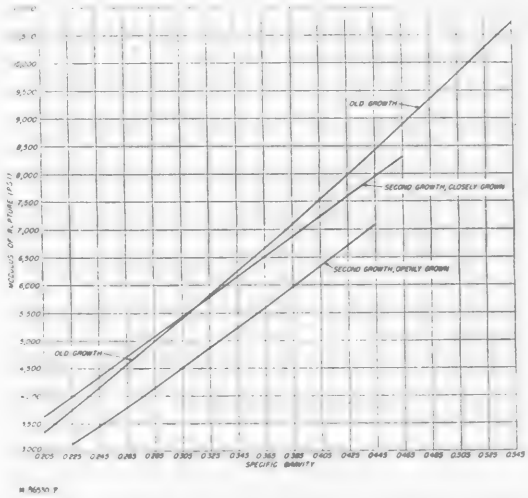

Fig. 4.—Chart showing relationships of specific gravity and modulus of rupture in bending tests of green old-growth redwood, closely grown second-growth redwood, and openly grown second-growth redwood. The curves representing the average trends show that for equal specific gravity the openly grown redwood is lower in bending strength than the closely grown second-growth and the old-growth redwood.

[4] Luxford, R. F. Effect of Extractives on the Strength of Wood. Journal of Agricultural Research, vol. 42, No. 12, pp. 801–826. June 15, 1931.

[5] From the test specimens the relationship was determined by using the formula $y = ax^b$ and solving for intercept and slope by the method of least squares after converting the formula to logarithm form. Modulus of rupture = y, specific gravity = x.

inch of cross section. The average of individual test specimens was 7,500 pounds. The bending tests from closely spaced second-growth trees averaged 6,100 pounds per square inch of cross section and ranged between 3,700 and 8,700 pounds. Wood from the openly grown second-growth trees was still lower in this strength property. It averaged only 4,600 pounds per square inch in the green tests and ranged between 3,000 and 8,700 pounds.[6]

It is worthy of note that bending strength is somewhat lower for comparable specific gravity values for the openly grown second-growth redwood than for the closely grown second-growth and for the old-growth. Somewhat similar results have been obtained from rapidly grown material of other coniferous species. The cause of this different behavior is being investigated.

In a dry condition at 12 percent moisture content comparative average modulus of rupture values for the three groups of trees were 10,000 pounds per square inch for old-growth, 8,300 for closely grown second-growth, and 6,400 for the wide-ringed openly grown trees. Table 1 contains average data for specific gravity, bending strength, hardness, and compression parallel to grain for the three groups of redwood trees when tested green and at 12 percent moisture content.

Data on other properties of redwood are also given in U. S. Dept. Agr. Technical Bulletin 479, "Strength and Related Properties of Woods Grown in the United States," and in U. S. Dept. Agr. Technical Bulletin 305, "Strength and Related Properties of Redwood." On the basis of wood of equal density, data for old-growth redwood compared favorably with ponderosa pine and Sitka spruce. The closely grown second-growth redwood compared more nearly to western redcedar and Engelmann spruce in the same properties, while the openly grown second-growth redwood was more like northern white cedar and cork bark fir. These comparisons are shown in Table 2.

Compression Wood

Compression wood ordinarily may be recognized by its appearance, which is darker than normal wood, and by the fact that when present logs are likely to be eccentric in cross section as viewed end on. In lumber it may be recognized by darker appearing streaks and relatively wider growth rings than in the adjacent wood. Compression wood, because of its undesirable shrinkage behavior, should be discarded for critical uses in manufacture and building. It appears likely that there will be a somewhat greater tendency for compression wood to form in second-growth redwood trees that are grown from sprouts about old stumps than from seedling trees, since in the sprout groups there is a tendency for the trees to lean away from each other at first to reach sunlight as they grow. This results in a sweep near the bases of the trees (Fig. 5). It is characteristic for leaning trees of all coniferous species to produce compression wood on the underside.

TABLE 1.—AVERAGE SPECIFIC GRAVITY, BENDING STRENGTH, HARDNESS, AND COMPRESSION PARALLEL TO GRAIN FOR OLD-GROWTH AND SECOND-GROWTH REDWOOD

		Specific gravity	Modulus of rupture P.s.i.	Hardness Lbs.	Compression parallel to grain. Maximum crushing strength P.s.i.
Old growth	Green	0.38	7,500	410	4,200
	12 percent moisture content	.40	10,000	480	6,150
Second growth, closely grown	Green	[1].32	6,100	350	3,280
	12 percent moisture content	.34	8,300	400	5,240
Second growth, openly grown	Green	[1].28	4,600	280	2,320
	12 percent moisture content	.30	6,400	340	3,810

[1]These specific gravity values differ from those given earlier in the text because fewer specimens were represented in the bending test.

[6]Markwardt, L. J. and Wilson, T. R. C. Strength and Related Properties of Woods Grown in the United States. U.S.D.A. Tech. Bull. No. 479. 1935.

TABLE 2.—SOME STRENGTH COMPARISONS OF REDWOOD WITH OTHER SPECIES OF SIMILAR AVERAGE SPECIFIC GRAVITY AT 12 PERCENT MOISTURE CONTENT

	Average specific gravity	Modulus of rupture P.s.i.	Compression parallel to grain. Maximum crushing strength P.s.i.	Hardness (side) Lbs.
Redwood (old growth)	0.40	10,000	6,150	480
Ponderosa pine	.40	9,200	5,270	450
Sitka spruce	.40	10,220	5,610	510
Redwood (second growth, closely grown)	.34	8,300	5,240	400
Western redcedar	.33	7,700	5,020	350
Engelmann spruce	.34	8,700	4,770	350
Redwood (second growth, openly grown)	.30	6,400	3,810	340
Northern white-cedar	.31	6,500	3,960	320
Cork bark fir	.30	6,900	4,110	290

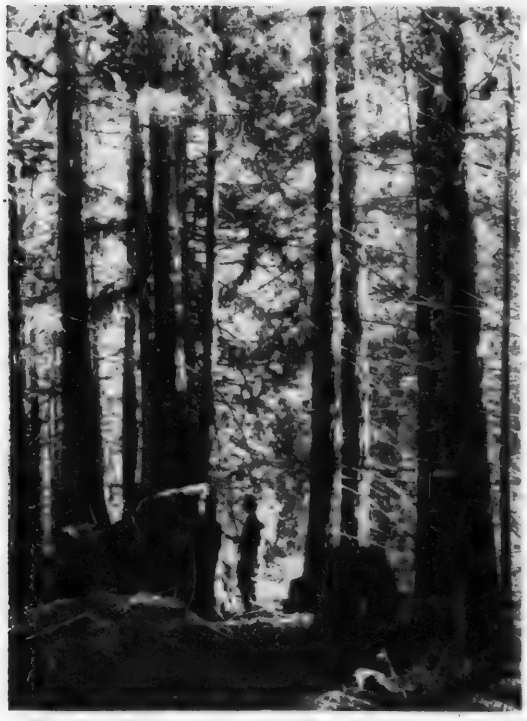

Fig. 5.—View in second-growth redwood sprout stand showing original old-growth stumps from which the new stand has originated.
(U. S. Forest Service Photo)

Shrinkage

Redwood is among conifers having very low volumetric and transverse shrinkages. Average values as shown in Table 3 are close to those of western redcedar and slightly below those of sugar pine.

TABLE 3.—SHRINKAGE OF REDWOOD

	In volume Percent	Radial Percent	Tangential Percent
Old growth	6.8	2.6	4.4
Second growth (closely grown)	7.4	2.4	5.0
Second growth (openly grown)	6.3	2.0	4.4
Western redcedar	7.7	2.4	5.0
Sugar pine	7.9	2.9	5.6

In general, sapwood shrunk slightly more than heartwood, but average differences between shrinkage of heartwood and sapwood were small (Table 3).

Longitudinal shrinkage of redwood has sometimes caused difficulty by the opening of butt joints in siding.[7] Investigations of such cases revealed the presence of compression wood in one or both of the pieces next to the openings. Usually, longitudinal shrinkage of lumber is disregarded because of its relatively small amount, which generally ranges up to about 0.30 percent of the green dimension for specimens dried to a moisture-free condition. Compression wood in redwood, as well as in other conifers, may shrink two to four times that amount, and in such cases warping or crooking results if a piece contains both normal wood and compression wood.

Again, in normal redwood the pieces containing mostly springwood shrunk more longitudinally than pieces with usual amounts of springwood and summerwood. The wood from near the center of trees having wide growth rings and a preponderance of springwood, particularly in second growth, may shrink enough more than the adjacent narrow-ringed wood to cause warping when both types of wood are contained in one piece of lumber. Wood from old-growth trees of exceedingly slow growth, when consisting almost entirely of springwood, also has relatively high longitudinal shrinkage. In the studies made, 93 percent of old growth, 86 percent of closely grown second-growth, and 76 percent of the openly grown second-growth had longitudinal shrinkage below 0.30 percent when dried from a green to an oven-dry condition.

[7] Koehler, Arthur, and Luxford, R. F. The Longitudinal Shrinkage of Redwood. The Timberman. Jan. 1931.

Conclusions and Recommendations

As in other species, redwood lumber of superior quality is found in the relatively narrow-ringed, clear portions of the large old-growth trees. Production of this high-quality wood in old-growth redwood trees has taken from 1,000 to 2,000 or more years. Second-growth trees, many considerably less than 100 years old, have grown rapidly in diameter and are of comparatively large size for their ages. The wood of such second-growth trees, particularly that near the pith, is characterized by very wide growth rings, having a very different natural appearance than that in old-growth timber. Also, the second-growth trees contain numerous knots from branches not yet removed in natural pruning, by which the proportion of clear lumber that can be cut from them is reduced. The wide-ringed wood, as has already been shown, is lower in density and strength. Only the outer, more slowly grown portion of second-growth trees closely approaches the quality of old-growth redwood lumber.

From a standpoint of forest management in second-growth redwood it appears that for the best timber quality, development of very wide-ringed growth should be discouraged by keeping young stands densely stocked at first. When the desired growth rate is established, it may be maintained by thinnings designed to keep ring width fairly uniform throughout the cross section. It is believed that lumber with more than eight growth rings per radial inch will be preferable and more satisfactory for many uses of redwood than that having wider growth rings. If young stands of redwood are pruned of lateral branches at an early age, further advantage will accrue by earlier production of clear lumber. In order to produce timber of high quality in comparatively short rotations, second-growth redwood timber stands should be given assistance through the best silvicultural practices when they are yet in the formative stages.

Discussion

F. F. Wangaard (Yale School of Forestry): Since redwood uses are primarily not structural, are these tests of strength a sufficient indication that second-growth material will be satisfactory?

John Reno (Pacific Lumber Company): I think so. As a representative of The Pacific Lumber Company, I appreciate the opportunity of commenting on Mr. Benson Paul's paper. Although The Pacific Lumber Company will not be faced with the necessity of utilizing second-growth redwood for many years to come, we agree that consideration of the comparative properties of old-growth and second-growth are appropriate at this time. It prepares us for things to come and enables calm evaluation without pressure.

It is our opinion that the uses for which redwood is found valuable today are the same purposes for which it will be desired to employ this species in the years to come. In this connection it is well to remember that redwood is not primarily a structural lumber; as a matter of fact, few redwood manufacturers make a practice of producing stress grade lumber. Great strength is not a requirement in most of the applications where its other valuable properties make it much in demand; therefore the lower specific gravity and concomitant lesser strength of second-growth redwood is not a serious consideration affecting its utilization in those fields where it is generally acceptable today.

Mr. Paul's paper discloses that there is very little difference in the average specific gravity of old-growth and second-growth redwood. The real variance is in the ranges of specific gravity, and here it must be noted that it is the second-growth that has the shorter range and hence produces a more uniform product. No deterioration in redwood's present gluing excellence is indicated by the differences in properties of old-growth and second-growth. Mr. Paul found that extractives (which influence the natural durability of redwood) vary from 5 to 28 percent in the heartwood of old-growth with an average of 10 to 15 percent while the variation in second-growth is 10 to 15 percent. This indicates the two growths are approximately equal in average extractive content.

As a matter of fact, it may develop that second-growth will prove to be about equal in other valuable respects to old-growth:

1. The transverse expansion and contraction will be no greater than in old-growth. Longitudinal shrinkage should not be a problem in properly selected, manufactured, and dried stock.

2. The painting properties of siding and finish manufactured, as is common practice, from the outer portion of the heartwood where uniform ring growth can be anticipated, should match the present superiority of redwood in this respect.

3. The wood should split less in nailing and screwing. The small difference in average specific gravity should result in only a moderate reduction in holding power, especially in the closely-grown second-growth.

During the interval between the present and the time when second-growth trees are our only source for redwood lumber, there will be, without doubt, more intensive investigations concerning the properties of this growth and more will be learned concerning its proper utilization.

These comments are offered to emphasize that undoubtedly it will be found that second-growth redwood can be used to advantage in about the same type of applications for which the old-growth is now being utilized.

Fatigue of Wood and Glued Joints Used in Laminated Construction

WAYNE C. LEWIS, *Engineer, Forest Products Laboratory,*[1] *Forest Service, U. S. Department of Agriculture*

This paper discusses test procedures for determining fatigue behavior of wood and glued wood constructions. Results are presented of tests of clear wood in tension parallel to the gram, of wood with glued scarf joints in tension parallel to grain, of a typical glued joint in shear, and of wood and glued wood in tension perpendicular to grain. Two species, Douglas fir and white oak, were used.

Appropriate S–N curves are presented and discussed, and conclusions are made with respect to the application of these data to glued laminated structures.

Introduction

GLUED laminated construction has come into its own during the last two decades. Because large timbers have become more scarce, hence more expensive, because of the considerable degrade introduced by drying timber of large cross section, and because laminations can be glued together to form permanently curved members, the advent of highly water- and mold-resistant glues has been the needed impetus to make the field of glued laminated construction one of major importance.

Often glued laminated structural members are used where many repetitions of major loading can be expected during the life of the structure. Because many stress-raisers are likely introduced in a member by gluing it up of smaller pieces, the question is often raised as to what will be the effect of the glued joints on resistance to fatigue. Another question often raised is, will the glue tend to fail in fatigue more rapidly than the wood adjacent to it.

The tests reported herein were undertaken to determine whether or not glued laminated construction can be expected to withstand repetitions of stress without failure as well as solid wood. Also, because data on the fatigue of wood in tension parallel to grain were not available, tests were made so that data could be compared with the results of tests of specimens with glued scarf joints.

Definitions

Engineering structures and machine parts are subjected to three types of stress—static, impact, and repeated. Principal stresses may be primarily one of the three types or combinations of them. A static stress is defined as a slowly applied stress that remains practically constant during the time the load is on the structure. The usual load on the floor system of a building is an example of a static stress. Impact stresses are produced by loads of short duration and are suddenly applied. Shock loading such as boats bumping a dock or dolphin produces impact stresses.

Repeated stresses are just what the name implies, stresses that are repetitive during the life of the structure. The number of repetitions may vary from a few thousand to many millions. The stresses produced by the loads on the stringers of a railroad bridge are an example of repeated stresses, each truck on each loaded car produces one repetition of stress. Thus, each train passing over a structure produces a substantial number of repetitions, which, when multiplied by the number of trains expected during the life of a railway bridge, brings the total to a figure large enough for the resistance to fatigue to become important.

Fatigue in engineering materials is defined as the progressive damage and failure that occurs when a structure or a part is subjected to repeated loads of a magnitude smaller than the indicated static strength. Failure may be sudden without visible damage prior to failure, or it may start as a crack, as in some metals, that spreads until the section under stress becomes too small to carry the load imposed on it, when the failure becomes complete.

There are certain terms used in fatigue work that are not general in materials testing, and that hence should be defined. The definitions that follow are in general conformity with those of American Society for Testing Materials.[2]

Maximum Stress, S_{max}—The highest algebraic value of stress in a stress cycle.

Minimum Stress, S_{min}—The lowest algebraic value of stress in a stress cycle.

Stress Ratio (also known as range ratio), R—The algebraic ratio of the minimum stress and the maximum stress in one cycle, that is, S_{min}/S_{max}.

Fatigue Life, N—The number of stress cycles that can be sustained for a given test condition.

[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2] Committee E-9, ASTM, 1949. Special Technical Publication No. 91. Manual on Fatigue Testing. 82 pp.

S–N Diagram—A plot of the stress against the number of cycles to failure. It is usually plotted S versus the logarithm of N.

Fatigue Limit (also known as endurance limit) S_e—The limiting value of the stress below which a material can presumably endure an infinite number of stress cycles, that is, the stress at which the S–N diagram becomes horizontal and appears to remain so.

Fatigue Strength, S_n—The greatest stress that can be sustained for a given number of stress cycles without failure.

Stress-raiser—Any abrupt change in cross section, such as a notch or hole, causes a concentration of stress; that is, because of the rearrangement of stresses caused by the change in cross section, stresses immediately adjacent to it are greater than the average calculated on the net section.

Description of Test Specimens

General

Two species were selected for the tests, Douglas fir as a representative softwood and white oak as a representative hardwood. They are two of the species most used for structural laminating, both having applications in boats, buildings, and bridges. The Douglas fir used in these tests was from five logs obtained from the Pacific Coast, hence represents "Coast" type of Douglas fir. The white oak was obtained from two sources in timber and plank form; (1) from the State of Indiana, and (2) from the Norfolk Navy Yard. Hence the geographical location of growth for part of the material is not known. A wide range of densities in each species was selected, so that the data obtained could be considered as representative as possible of the species used for the limited program involved.

Three types of glued joints were considered important because of the frequent occurrence in a glued laminated member of the following: (1) scarf joints as used in end-joining boards in individual laminations when stressed in tension, (2) shear parallel to the grain along glue lines, as is introduced because of discontinuities in adjacent laminations, and (3) tension perpendicular to the glue line, as would be introduced in the glue lines between laminations when tensile forces are present perpendicular to the grain in the wood.

[3] American Society for Testing Materials, "Standard Methods of Testing Small Clear Specimens of Timber." D143–50, Part 4, ASTM Standards, 1949. Pages 617–659.

Material selected for test was straight-grained and free from defects such as knots, decay, and abnormal growth. The specimens were all glued with a room-temperature-setting resorcinol-resin adhesive with mechanical pressure applied while the glue was setting. Specimens were fabricated on commercial woodworking equipment and were of a quality no better than could be expected in any well-controlled, wood-manufacturing operation. All material was kiln-dried at the Forest Products Laboratory to approximately 12 percent moisture content and further conditioned at 75° F. and 64 percent relative humidity prior to and after fabrication of specimens.

Tension Parallel to Grain

Approximately 260 tension-parallel-to-grain specimens were prepared, of which about one-half were of each species. Because there were no data on solid specimens (without scarf joints), there were an equal number of solid specimens and those with scarf joints so that a comparison could be made between the fatigue resistance of the specimens with the glued-scarf joints and those of the solid wood. The specimen used for these tests is detailed in Fig. 1. It is the same as the standard specimen[3] for wood, except that a uniform width section 5 inches long was used to provide sufficient length for the scarf joints. A 1:8 slope of scarf joint, though steeper than usually recommended, was selected for these tests because it was deemed desirable that the slope used have as severe effect on the fatigue behavior as practicable. It was considered that any results from so few tests should be conservative. The scarf joint was made across the ½-inch dimension; therefore, the length of scarf parallel to the axis of the specimen was 4 inches.

Scarf joints were prepared in flat-grained boards ½ inch thick, after which ¼-inch slabs were glued to the faces of the board at the ends of the 30-inch length to provide the required 1-inch thickness at the ends of the specimen. The steps in the preparation of the scarf-jointed specimens are detailed in Fig. 2. All specimens were shaped to final cross section in a high-speed spindle shaper. The solid specimens were prepared from the ends of the same planks as were used for the scarf-jointed specimens, so that, in effect, the solid specimens in each set were longitudinally matched to the scarf-jointed ones in the same set.

Five different logs were represented in the tests of Douglas fir, and 11 different timbers were represented in the tests of the specimens of white oak.

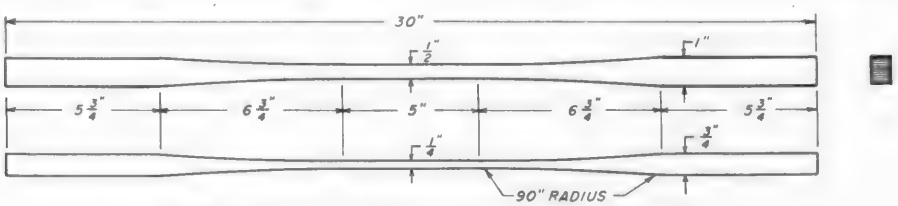

Fig. 1.—Tension-parallel-to-grain specimen for fatiuge test.

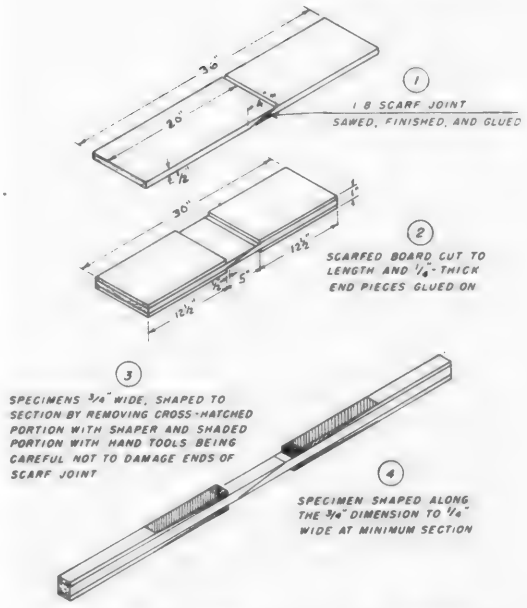
1
1:8 SCARF JOINT
SAWED, FINISHED, AND GLUED
2
SCARFED BOARD CUT TO LENGTH AND 1/4" THICK END PIECES GLUED ON
3
SPECIMENS 3/4" WIDE, SHAPED TO SECTION BY REMOVING CROSS-HATCHED PORTION WITH SHAPER AND SHADED PORTION WITH HAND TOOLS BEING CAREFUL NOT TO DAMAGE ENDS OF SCARF JOINT
4
SPECIMEN SHAPED ALONG THE 3/4" DIMENSION TO 1/8" WIDE AT MINIMUM SECTION

Fig. 2.—Sketch showing steps in the preparation of tension-parallel-to-grain specimen with scarf joint in net section.

Specimens were prepared from planks in groups of 5 to 8 with the specimens in each group tangentially matched.

Laminated Glue Shear

The total number of specimens in this series was 80, of which 40 were Douglas fir and 40 were white oak. The glue-shear specimen is detailed in Fig. 3. The specimen was designed so that tension loading of the specimen produced shear along the two glue lines, which had a total area in shear of 8 square inches. Fig. 4 shows how the specimens

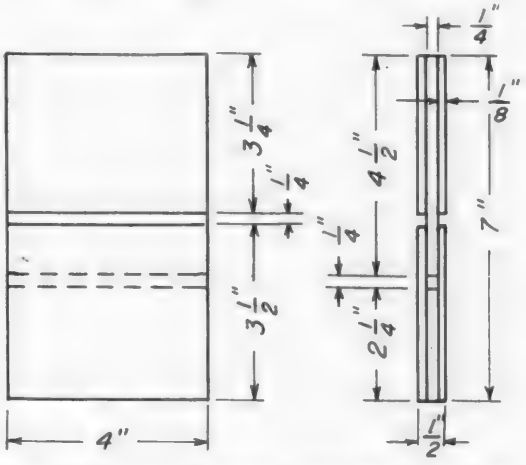

Fig. 3.—Laminated glue-shear specimen for fatigue test.

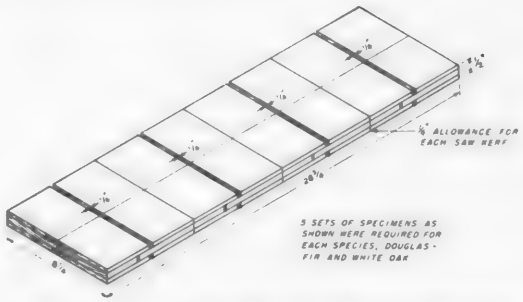

Fig. 4.—Layout of laminated glue-shear specimens showing the way the specimens were glued into a panel and later sawed to provide eight test specimens that were essentially matched to each other.

were glued together of matched material in groups of eight. The assembled panels were trimmed, and the individual specimens sawed out after gluing. Because the material in each lamination was essentially flat-grained, individual specimens in each group of eight could be considered as being either tangentially or longitudinally matched to the others in the same group. Five different logs were represented in the tests of Douglas fir, and five different planks were represented in the tests of white oak.

Tension Perpendicular to Grain

Approximately 90 specimens were prepared for this series. Because of the great variability in results of tests in tension perpendicular to grain in wood and because this property is practically never used directly in design, only Douglas fir was used in these tests. The specimen used in this series is detailed in Fig. 5. This specimen is different from the standard

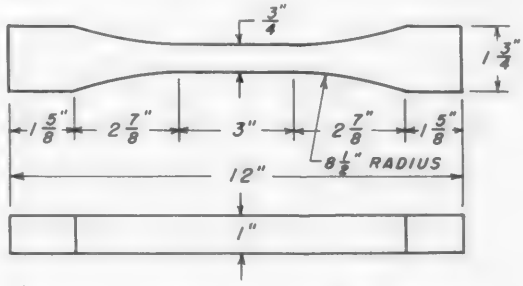

Fig. 5.—Tension-perpendicular-to-grain specimen for fatigue tests.

used for wood[3] because it was considered desirable to eliminate all possible concentrations in stress at the net section, as well as those that might be introduced by the grips used in the standard test. Stress-raisers such as these are likely to have a greater effect in fatigue than in static tests.

The tension-perpendicular-to-grain specimens in each group were matched to each other in the longitudinal direction of the grain in the wood; that is, they were prepared by sawing strips 1¾ inches wide

across the boards. One-half of the specimens in each group had a glued joint in the center of the length of the specimen. This joint was made in the board before the individual specimens were sawed, so that the quality of the joints in the specimens of a set was essentially the same. Final shaping of the reduced center section was done with a high-speed spindle shaper. Five different logs were represented in these tests.

Methods of Test

Controls

The static control strength of the different types of specimens was determined from tests of representative specimens in each group from each log or plank in conformity with established practices for static tests of wood. Tests were conducted in universal-type testing machines at rates of loading comparable with those required for standard tests of wood.[3]

Self-alining Templin-type grips were used for the control tests in tension parallel to grain and tension perpendicular to grain to insure that the loading was parallel to axis of specimens. Loading was at the uniform rate of 0.05 inch per minute for the tension-parallel-to-grain specimens and 0.04 inch per minute for the tension-perpendicular-to-grain specimens.

Pin-connected fittings, the same as for the fatigue tests, were used in conjunction with plates glued to the sides of the specimens at their ends to produce shear stresses by tension-loading in the laminated glue-shear specimens. The uniform rate of separation of the heads of the testing machine was 0.025 inch per minute.

Fatigue Tests

The fatigue tests were made in axial-loading fatigue machines, one of which is shown in Fig. 6. Two specimens can be tested simultaneously in this machine, each to a maximum repeated load of as much as 4,000 pounds. Other machines with capacities of 10,000 pounds were used when maximum repeated loads were large enough to require this capacity.

Both sides of these machines are driven from one shaft to which the adjustable eccentrics are attached. A V-belt drives the shaft, and by using different sized pulleys, different speeds are obtained. A rate of 900 cycles per minute was used on all tests reported herein. Automatic devices are provided for counting the number of cycles for each side of the machine. The setting of the eccentric is dependent upon the variation of load desired. The mean load (preload) is applied to the specimen by means of the upper loading screw, and the desired variation for each cycle is applied through the reciprocating loading arm, which is attached to the adjustable eccentric by the vertical connecting rod.

Static loads are determined from readings of the load-indicating dial bar (Fig. 6, F). The dial measures the deflection of the cantilever loading arm, which is directly proportional to the load. (This dial bar is removed when the machine is operating.) Due to inertia effects in the arm and other moving parts, however, the alternating stress amplitude is greater when the machine is operating than is indicated by the dial bar. This difference was

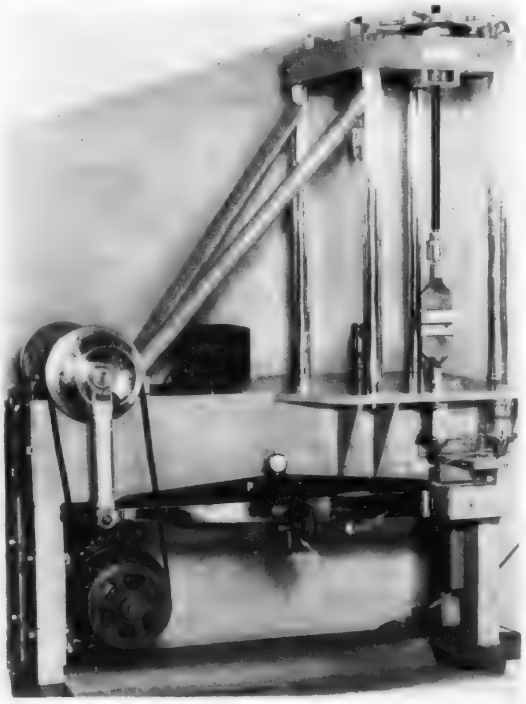

Fig. 6.—Axial-loading fatigue machine showing: (A) upper loading screw (B) specimen (specimen shown is the one for the laminated glue-shear test) (C) lower loading screw (D) electric strain gages for determining corrections for dynamic effects (E) horizontal loading arm (F) calibrated dial bar for determining static loads (G) adjustable eccentric (H) electronic cut-off switch for stopping machine.

determined to be directly proportional to the alternating stress amplitude by using electric-type strain gages, so that when the dynamic throw factor (correction factor for inertia effects) had been determined it was possible to calculate the static variations in load that would give the desired variations when the machine was operating.

Each side of each machine is equipped with an electronic shut-off mechanism (Fig. 6, H) that turns off the motor when, because of yield or failure of the specimen, the load decreases more than a predetermined amount. The operation of the shut-off mechanism is based on the fact that the deflection in the cantilever loading arm decreases with a decrease in load. The amount of reduction in load necessary to operate the relays shutting off the machine is determined by the setting of the cut-off

switch, which can be adjusted so that a reduction in load of as little as 20 pounds will stop the machine. Thus, it is possible with proper monitoring to achieve essentially constant loads with a constant-deformation type of machine.

Because the temperature of a specimen tends to increase during test, due to energy absorbed in stressing, and because wood has a low coefficient of thermal conductivity, fans were used to cool the specimens during test. An increase in temperature during test would tend to decrease the moisture content of the specimens and to change its strength. An appreciable rise in temperature would also be undesirable because it is unlikely to occur in service. All fatigue tests were made in a controlled atmosphere of 75° F. and 64 percent relative humidity.

A difficulty in making direct-stress fatigue tests of wood is in the proper gripping of the specimens. Wedge-type grips as used in static tests are obviously not applicable, and if bolted connections are used, the bolt holes tend to enlarge during test and the wood may split as a test progresses. This difficulty was resolved satisfactorily by gluing steel plates to the sides of specimens near each end. Fig. 7 shows the three types of fatigue specimens, the plates glued to them, and the pin-connected fittings used to insure that the center of loading coincided with the axis of the specimens. Thin sheets of yellow birch or walnut veneers with the grain parallel to the direction of the applied load were bonded to each face of the metal loading plates in a hot press. The plates with the veneer bonded to them were then glued to the specimens by a room-temperature-setting resorcinol-resin adhesive. This method offered several advantages over gluing plates directly to the specimens. After completion of one test the plates were removed, turned over, and glued to another specimen. Because the specimens were not subjected to heat to set the glue line, less conditioning was required before test.

Results of Tests

Tension Parallel to Grain

The strength of each of the groups of fatigue specimens was determined from static tests of about 50 Douglas fir and 50 white oak specimens. In general, of a group of 8 specimens, 3 were controls and 5 were fatigue specimens. If the plank was narrow so that only 5 specimens could be obtained, 2 were tested statically to serve as controls.

The tensile strengths for control specimens of solid wood in the Douglas fir averaged 14,370 pounds per square inch for an average specific gravity of 0.47 (based on oven-dry weight and volume). Tensile strengths of individual specimens varied from 9,000 to 20,900 pounds per square inch with a corresponding range in specific gravity of from 0.40 to 0.55. The tensile strengths for the control specimens of solid wood in the white oak averaged 16,620 pounds per square inch for an average specific gravity of 0.66. Tensile-strength values for individual specimens varied from 9,000 to 24,300 pounds per square inch with a corresponding range in specific gravity of from 0.54 to 0.83.

The tensile strengths for the controls of scarf-jointed specimens in the Douglas fir averaged 11,780 pounds per square inch with individual strength values ranging from 8,700 to 16,100 pounds per square inch for the essentially same range in specific gravity as for the solid specimens. This indicates that, on the average, the efficiency of the scarf-jointed specimens was 82 percent of the strength of the solid specimens. The tensile strengths for the controls of the scarf-jointed specimens of white oak averaged 13,270 pounds per square inch with individual strength values ranging

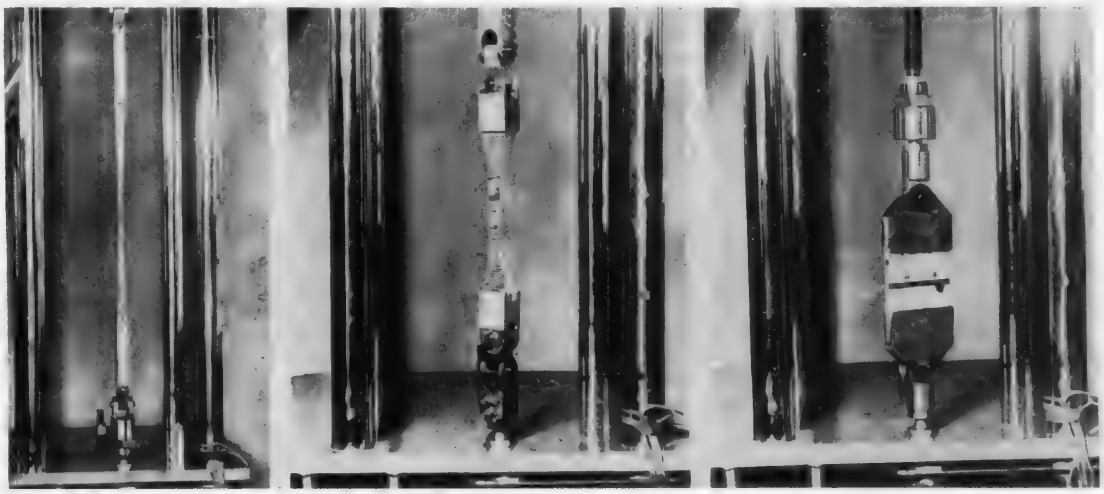

Fig. 7.—Set-up for tests in axial-loading fatigue machines showing specimens and steel plates glued to specimens to transmit stresses from pin-connected fitting to specimens. Specimen on left is for tension-parallel-to-grain test, center for tension-perpendicular-to-grain test, and on right for laminated glue-shear test.

from 6,600 to 21,400 pounds per square inch with essentially the same range in specific gravity as for the solid specimens. This indicates an average efficiency for the scarf-jointed specimens in white oak of 80 percent of the strength of the solid specimens.

Each fatigue specimen was stressed repeatedly to some predetermined maximum stress based on the control strengths of the static-test specimens matched to it (the average of the ultimate tensile strengths parallel to the grain of the two or three static specimens in the same group). Because it was impractical from a testing standpoint and because only rarely in actual service is all load removed from a structure, the minimum stress for each cycle of stress was arbitrarily selected to be 0.10 of the maximum for that cycle ($R = 0.1$). Approximately 40 specimens were tested for each of the four groups of tests in this series, solid Douglas fir, scarf-jointed Douglas fir, solid white oak, and scarf-jointed white oak. Different specimens were subjected to repeated stresses that were different percentages of the static control strengths, so that enough representative points were obtained to estimate the S-N curve for each of the four groups.

The resultant S-N curves are presented in Figs. 8 and 9. Fig. 8 presents the curves for solid and for scarf-jointed Douglas fir, and Fig. 9 the similar curves for white oak. Examination of these curves indicates that the scarf-jointed specimens withstood the repeated stresses as well as did the wood without any joints in them. The differences between the curves for scarf-jointed material and the solid material for each species is no greater than can be readily attributed to the relatively few data that located the curves. The location of the curves was by inspection, and only if there were a large number of tests could any more accurate means be employed.

From the data obtained in the fatigue tests of these two species it is believed that the following conclusion is warranted: That if proper reduction in the working stress is made for the weakening effect of scarf joints on the static strength of a material when stressed in tension parallel to grain, then the structural member can be considered to be as resistant to fatigue in tension as though the member were of solid wood.

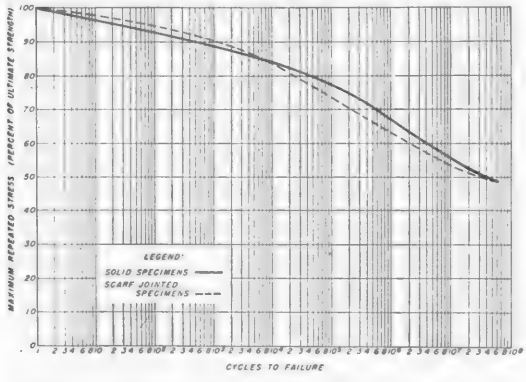

Fig. 8.—S–N curves in tension parallel to grain for solid and scarf-jointed Douglas fir. Ratio of minimum repeated stress to maximum repeated stress for each cycle (R) was 0.10 for all tests.

Further, it appears from the S-N curves for the condition of loading used ($R = 0.10$) that the fatigue strength in tension parallel to grain for wood for 30 million repetitions of stress is in the neighborhood of 50 percent of the static strength, if the material has no major defects present and is essentially straight-grained. The S-N curves for the two species are presented in Fig. 10.

The failures in fatigue were in every way similar in appearance to those from the control tests for the scarf-jointed specimens. There was no indication of any breakdown of the glue from the repeated loading. The failures in the solid specimens in fatigue were likewise similar to those tested statically, with none of the brash appearance that is so characteristic of metals. At higher levels of stress, failure was sudden and complete with little or no indication that failure was imminent. At the lower levels of stress, failures were likely to be progressive with as little as one annual ring failing at a time. That the

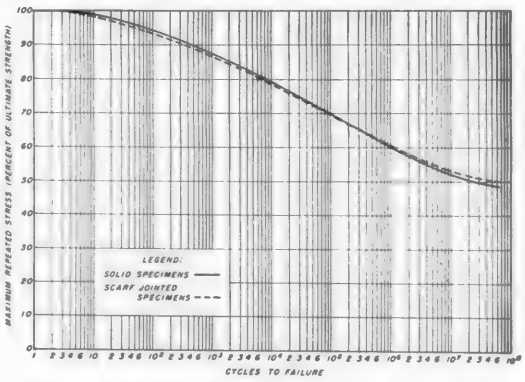

Fig. 9.—S–N curves in tension parallel to grain for solid and scarf-jointed white oak. Ratio of minimum repeated stress to maximum repeated stress for each cycle (R) was 0.10 for all tests.

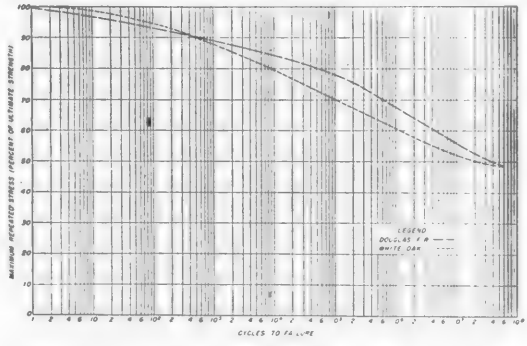

Fig. 10.—S–N curves in tension parallel to grain for Douglas fir and white oak clear, straight-grained wood free from defects. Ratio of minimum repeated stress to maximum repeated stress for each cycle (R) was 0.10.

fatigue failures were so similar in appearance to the static failures makes it seem probable that some structural failures in service may have been attributed to overload when, in reality, they may have been fatigue failures.

The fatigue data in tension parallel to the grain was quite variable, as is indicated by Fig. 11, which

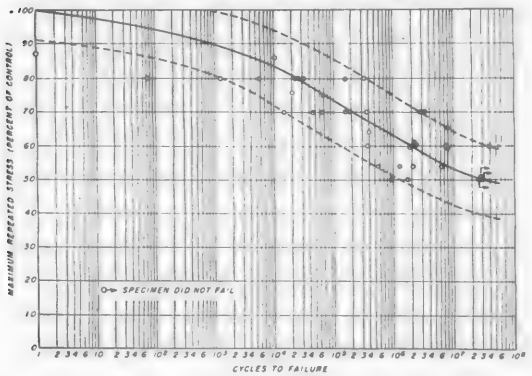

Fig. 11.—Results of individual tests and S–N curve for 1:8 scarf-jointed specimens of Douglas fir in tension parallel to grain. Ratio of minimum repeated stress for each cycle (R) was 0.10.

shows the individual test results for the scarf-jointed Douglas fir specimens plotted with the resultant S-N curve. This apparently large scatter of test results can be explained by two things. First, all fatigue data have a larger scatter than do data from static tests. Fatigue behavior of materials is affected greatly by microscopic stress-raisers in a material as well as by external stress-raisers such as notches and other abrupt changes in cross section. Second, because the greater variability in wood over most materials makes it very difficult to estimate accurately the strength of one piece of wood from the strength of another piece adjacent to it. Tension parallel to the grain is one of the more variable strength properties.

Laminated Glue Shear

The static strength of each of the groups of laminated glue-shear specimens was determined from static tests of 15 specimens of each of the two species. There were three specimens tested statically from each group of eight. The Douglas fir specimens had an average calculated shear stress at failure of 748 pounds per square inch with individual values ranging from 616 to 900 pounds per square inch. The white oak specimens had an average calculated shear stress at failure of 1,304 pounds per square inch with individual values ranging from 1,090 to 1,455 pounds per square inch.

Because the range in individual values in any one group was in many instances almost as large as in the entire number of specimens tested, and because this test was the test of a joint in shear, the average control value for the entire series for each species was used as the ultimate strength of each specimen. Better agreement among fatigue-test results was obtained with this procedure than by using the results of the controls for each panel.

Each fatigue specimen was loaded repeatedly to some predetermined maximum stress based on the control strength so that representative points for a S-N curve would be obtained. The S-N curve was located by inspection to pass through the mean of the plotted points of the test results. The S-N curves obtained for shear, as produced by the type of specimen used in these tests, are presented for both Douglas fir and white oak in Fig. 12. Examination

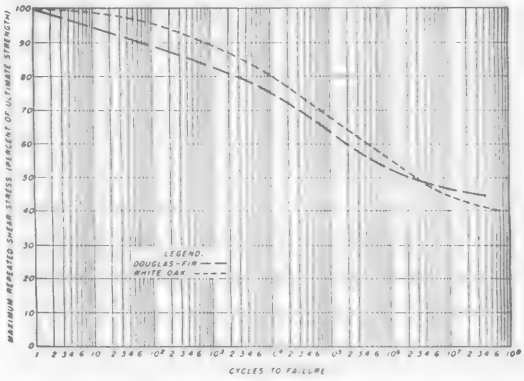

Fig. 12.—S–N curves in shear in laminated glue-shear for Douglas fir and white oak. Ratio of minimum repeated shear stress to maximum repeated shear stress for each cycle (R) was 0.10.

of these curves indicates that on a percentage basis the Douglas fir may be slightly more susceptible to fatigue for repetitions from 1 cycle to about 3 million cycles and less susceptible to fatigue failure for cycles in excess of 3 million. This difference is not believed to be significant because the number of tests represented is too small to locate exactly the S-N curves. These tests, however, do indicate a fatigue strength for 30 million repetitions of stress, for a construction of this type with the 90-degree re-entrant angle (constituting a stress raiser), of something in the range of 40 to 45 percent of the static strength in shear for this condition of loading ($R = 0.10$). This would amount to approximately 300 pounds per square inch for the Douglas fir and 500 pounds per square inch for the white oak. Actual working stresses in designs incorporating this type of joint are considerably lower than these amounts, so that the danger of fatigue failure from this type of stressing should be minor.

The failures in both the controls and the fatigue tests were almost entirely in shear of the wood in the area immediately adjacent to the glue line. Occasionally in the tests of white oak the failure would be a combination of shear and tension parallel to the grain in the wood. A typical failure is shown in Fig. 13.

The results for the laminated glue-shear tests were not so scattered as for the tests in tension

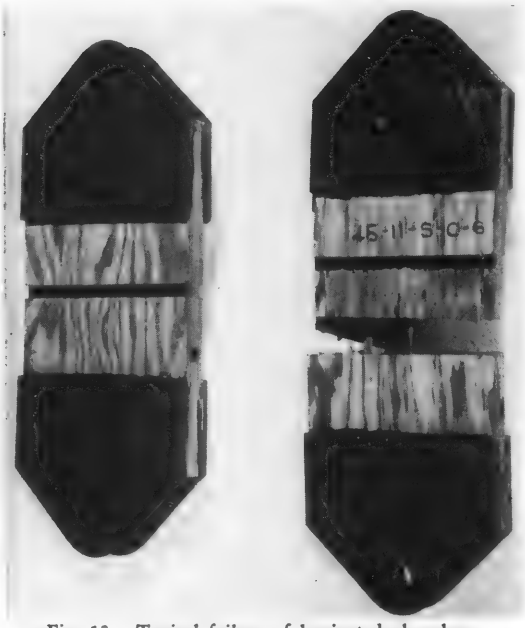

Fig. 13.—Typical failure of laminated glue-shear specimen of Douglas fir.

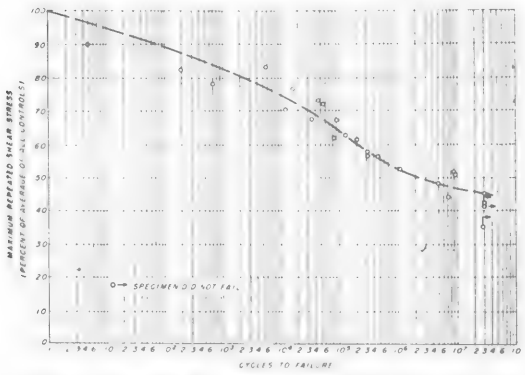

Fig. 14.—Results of individual tests and S–N curve for laminated glue shear in Douglas fir. Ratio of the minimum repeated stress to the maximum repeated stress for each cycle (R) was 0.10.

parallel to grain. Fig. 14 shows the individual test results for Douglas fir laminated glue-shear tests with the resultant S-N curve. The probable reasons for this are that the shear strength of wood is not so variable as for tension parallel to grain and, probably more important, that the concentrations of stress produced by the 90-degree re-entrant angle at the notch has a greater effect on the strength of the joint than the quality of the wood itself.

Tension Perpendicular to Grain

The results from the tension-perpendicular-to-grain tests were more qualitative than quantitative. The results from both the static and the fatigue tests were so variable that it was not possible to estimate the location of the S–N curve. The tensile strength of wood perpendicular to grain is extremely variable and is probably the cause of the large scatter in test results. For example, the tensile strength of the control specimens varied from a low of 254 pounds per square inch to a high of 494 pounds per square inch and averaged 402 pounds per square inch. Also, these specimens were so fragile that it was easy to damage them during fabrication or while handling.

That none of the specimens with a glue joint failed anywhere near the joint when tested in fatigue is significant. It is well known that when edge-gluing boards it is not too difficult to get a glue bond that is stronger than the wood across the grain. In fact, it is the usual procedure of the woodworker to test a scrap sawn from the end of an edge-glued board by bending it until it fails and noting whether or not the failure is in the bond. From the fatigue tests it is apparent that the glue line is not any more critical in fatigue than it is in static loading.

Summary of Results and Conclusions

On the basis of the results of the tests in fatigue discussed herein, (1) in tension parallel to grain of solid wood, (2) in tension parallel to grain of specimens with 1:8 glued scarf joints, (3) in laminated glue-shear (typical of points where there is a discontinuity in one lamination and stress must be transferred by shear to the two laminations adjacent to it), and (4) in tension perpendicular to grain (where there is a glued joint comparable with those produced by edge-gluing boards), it appears that the following conclusions are warranted, provided that a glue as resistant to fatigue as a resorcinol resin is used.

1. That glued-laminated construction can be used with confidence in the resistance to failure in fatigue in the same applications where solid-wood construction has proven satisfactory.

2. That scarf joints with a 1:8 or flatter slope in individual laminations can be expected to withstand repetitions of stress as well as a continuous lamination, provided reductions in design stresses are made for the reduction in static strength.

3. That the fatigue strength for dry wood in tension parallel to grain at 30 million cycles of stress is about 50 percent of the static strength, provided the wood is straight-grained and has no defects and the condition of loading (stress ratio of 0.10) is the same as used in these tests.

4. That there was no evidence in any of the tests that the glue tended to deteriorate due to fatigue any faster than the wood around it.

5. That the fatigue strength of a glue joint in shear is 40 to 45 percent of the static strength when there is a stress-raiser similar to the re-entrant angle used in these tests present and the condition of loading (stress ratio of 0.10) is the same as used in these tests.

6. That there is no tendency for a glue line to deteriorate in fatigue any faster than the wood itself when tensile stresses are perpendicular to the grain and to the glue line.

Discussion

Mr. X: In your experiments, what was the length of time between bonding and testing?

Mr. Lewis: About 30 days, minimum. All specimens were glued at nearly the same time, after which they were further conditioned before test in a controlled temperature-humidity room for that period. Some fatigue tests were made as long as a year after the specimens were prepared.

Dr. Irving H. Isenberg (Institute of Paper Chemistry): In actual structures, can suitable inspection procedures be used to detect imminent fatigue failures?

Mr. Lewis: Usually design stresses are much lower than the point at which failure occurs as a result of fatigue. In some structures, however, such as aircraft, inspectors are trained to watch for cracks and other evidence of fatigue failure. Generally speaking, though it could be possible for a fatigue failure to occur in a wood or glued-wood member, subjected to repeated stress, without any visible indication that failure was imminent. Because failures due to fatigue are so similar in appearance to those due to other causes it may be difficult to determine whether an actual service failure may have been due to fatigue or to a load that exceeded the ultimate strength of the structural part.

E. George Stern (Virginia Polytechnic Institute): Did you observe the increase in temperature of the test specimens during the testing and particularly at the time of failure?

Mr. Lewis: We made an attempt to cool the specimens during the test by air blast because fatigue loading in an actual use such as a bridge occurs over a long period of time, usually many years. In that case there would be no temperature effect. In the tests, however, the increase in temperature was less than 10° F., and any effect from the temperature rise during test could not have been appreciable, because moisture contents of the wood after test were essentially unchanged from those before test. Failure in fatigue usually occurred in a relatively few cycles once it started, so any extra heating during the period that failure was occurring had little effect on the total number of cycles of stress before failure.

Eric Anderson (New York State College of Forestry): Have you done any testing in fatigue at very low temperatures?

Mr. Lewis: The only work being done is in the field of metal to metal bonding. In these tests the metal often fails before the bond. Metal to metal glue tests show increased fatigue strength at low temperature. Similar tests will be conducted on wood in the future. That is at a given level of stress, a specimen will withstand a greater number of cycles before failure if at —70° F than if at room temperature.

Mr. X: Do wood or wood-base materials react in fatigue the same as metals?

Mr. Lewis: Wood or wood-base materials are subject to failure in fatigue (due to repeated stresses) in the same way, but not necessarily in the same degree as metals. Indications are that in terms of percent of strength the fibrous materials such as wood may not be as susceptible as are most crystalline materials such as metals.

Mr. X: How should fatigue data be applied to design criteria?

Mr. Lewis: Generally it should be a separate consideration. In a structure or member subjected to repeated loads, estimated stresses should not exceed the indicated fatigue strength for the number of cycles of stress expected during the life of the structure.

Mr. X: What are some of the differences between the techniques for testing wood and similar materials as compared to tests for metals?

Mr. Lewis: These materials all have lower moduli of elasticity than do metals so fatigue testing machines must have capacity for greater movement during each application of stress. Also, more work is done per cycle and because coefficients of thermal conductivity are much lower, speeds of cycling must be slower since the work done on the specimen is dissipated as heat. Usually some type of cooling such as a fan is warranted. Difficulties of fastening the specimen are usually more complex. Some such technique as was used in these tests, where the plates were glued to the specimen may be necessary.

Mr. X: What types of fatigue tests are most applicable to wood and wood-base materials?

Mr. Lewis: Direct stress types of tests rather than rotating beam or flat plate, are considered more applicable because the entire cross-section is subjected to tensile, compressive or shear stressing.

Evaluating Wood Preservatives

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This report suggests various tests that are helpful for the evaluation of wood preservatives and summarizes the important features of procedures commonly used in these tests.

Introduction

THE accurate evaluation of a wood preservative is a difficult and time-consuming job. The quality of some products of industry can be easily determined in laboratory tests and their fitness for their intended use determined within a matter of hours or days. But such is not the case with wood preservatives.

In evaluating a new preservative it is desirable to begin with laboratory screening tests. If the preservative in such testing shows up favorably it can then be tried out in accelerated tests on wood stakes in the field. This is desirable since field conditions cannot be reproduced in the laboratory. Actual service tests are necessary to determine the extent of protection a preservative will provide to specific wood products, such as telephone poles, crossties, fence posts, or bridge timbers.

Even in the case of a poor preservative the time required for a service test may be several years. Service tests may need to run for 15 to 20 years or longer to furnish accurate comparisons of the better wood preservatives.

It is unfortunate that during this period of waiting persons developing new preservatives are often discouraged and look to more lucrative fields than that of wood preservation. On the other hand large purchasers of treated wood should hesitate to take the risk involved when insufficient evidence of satisfactory performance of a treated product is at hand.

Although a satisfactory shortcut or a substitute for service tests has not yet been developed, laboratory and accelerated field tests on wood preservatives are highly important and useful tools. Laboratory tests must be used for determining the chemical and physical properties of a potential preservative. Laboratory toxicity tests, soil-block tests, and accelerated field tests are particularly useful for screening out ineffective materials and for focusing attention on preservatives that show promise. In times of shortage of standard preservatives, these tests furnish some evidence to guide the wood user and to help him in selecting preservatives that are most likely to meet his requirements.

Considerable attention has been given recently to a test program by the U. S. Forest Products Laboratory and several cooperators in which the same preservatives are included in coordinated laboratory tests, accelerated field tests, marine borer tests, and a post service test. (*3*).[4] This should furnish a good opportunity for the correlation of the results of accelerated and service tests.

It is the purpose of this report to call attention to some of the better recognized procedures used in evaluating preservatives through laboratory and field tests of various types.

Laboratory Tests

The extent to which a wood preservative can be expected to be acceptable from the standpoint of meeting certain well recognized requirements can be determined through several tests in the laboratory. In order to be generally useful a wood preservative must (a) be toxic to the organisms that degrade or destroy wood, (b) have suitable permanence, (c) have satisfactory penetrating properties, (d) be safe to handle and use, and (e) be harmless to wood and metal. In the case of certain special products, such as millwork or manufactured articles, the preservative may be required to be odorless, nonswelling, moisture repelling, fire retardant, or to have combinations of several of these or other properties. In such cases it may also be required that the preservative not discolor or interfere with the paintability of the wood. The relative importance of the different requirements depends upon the character of the product treated, the purpose for which it is to be used, and the conditions of service. The preservative, of course, must be inexpensive but this is a question of economics and cannot be determined through laboratory tests. Toxicity tests, however, may indicate whether or not a material is likely to be costly on the basis of the quantity necessary to kill a test fungus.

Permanence

Since treated wood must last many years in order to give satisfactory service, it is apparent that a preservative must have a considerable degree of permanence. No preservative is acceptable that evaporates readily or that otherwise disappears in a short time from the wood or changes chemically into compounds that are ineffective. Benzene and turpentine are examples of liquids that are toxic but that evaporate from the wood too quickly to give the desired protection. Complete resistance to evaporation, leaching, or chemical change is not required, but the rate at which the preservative becomes ineffective must be so slow that adequate

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[4] Numbers in parenthesis refer to citations listed at the end of this report.

protection is afforded over a sufficient period of time.

Laboratory tests fail to include such varied combinations of factors as leaching, vaporization, weathering, and chemical changes existing when treated wood is used in service. Consequently there is no adequate laboratory test for determining the permanence of a preservative. Laboratory tests, however, can show the volatility, leachability, and chemical stability of preservatives and thus be useful tools. One laboratory weathering test, to indicate the relationship of toxicity to permanence has been developed in which treated wood blocks are exposed to a continuous cycle of passing through heat, moving air, and fresh water (*22*).

Volatility—The volatility or loss of preservative by evaporation from the wood in service is governed largely by the vapor pressure of the preservative at the temperature to which wood in service is exposed. Data on the vapor pressures of many chemicals are not so complete as may be desired, but the boiling point of most chemicals is known and constitutes a fairly good index of their volatility at ordinary atmospheric temperatures. The volatility of oils and mixtures of oils can be studied by making fractional distillation tests by the standard distillation procedure in use for coal-tar creosote, and comparing the results with those obtained from creosote. With organic solids, determinations of melting point and boiling point are useful, as well as behavior on continued heating at different temperatures. Inorganic solids seldom are volatile enough to give concern.

Leachability.—When treated wood is in contact with the ground or water, the preservative may be gradually dissolved out of the wood by the water or soil chemicals. No chemicals are absolutely insoluble in water, but some have such low solubility that they leach very slowly. The toxic constituents of coal-tar creosote, for example, have such low solubility in water and leach so very slowly that some creosotes have given protection to structural timbers for periods greater than 50 years. Although creosoted wood usually does not last that long, its ultimate destruction is ordinarily caused by factors other than leaching. Even preservatives that are readily soluble in water, if originally injected in suitable quantities, require some years to leach to the point where they no longer afford protection. When preservatives are sufficiently soluble to make water solutions of satisfactory strength for treatment, differences in their solubility are not a measure of resistance to leaching. For example, zinc chloride is soluble in water in practically all proportions while the solubility of sodium fluoride is only about 4 percent at normal atmospheric temperatures. Yet the rate at which they leach from wood is very similar.

There is no standard method of making leaching tests, but a common method is to impregnate blocks of wood, submerge either the blocks or sawdust from the blocks in water for definite and repeated periods of time and make analyses of the leach water to determine the amount of leached chemical it contains (*8, 11*). Where complex chemical compounds are involved or where the original preservative retention is not definitely known it may be necessary to determine the preservative content from samples of treated wood sawdust before, as well as after leaching (*9*). With some chemicals, such analyses can be made rather simply and accurately. Other chemicals require much more inconvenience, time, and expense; for some, satisfactory methods of analysis may not even be available. On the whole, comprehensive and reliable leaching tests are both expensive and time consuming.

Chemical stability.—This property of a preservative in wood is one of the most difficult to measure in the laboratory. It is sometimes possible to classify a material as unpromising because of its known tendency or the tendency of chemically related materials to decompose spontaneously or to react with water, oxygen, or carbon dioxide. Calcium cresylate for example, in the presence of carbon dioxide, is converted to nontoxic calcium carbonate. The fact that a material reacts vigorously with some constituent of wood at a high temperature leads one to suspect that a slow reaction may take place at ordinary temperatures, even though such reaction is not at once apparent. Bombs immersed in hot water and agitated have been used to study the effect of oxygen on different types of creosote (*25*). There are no standard tests for chemical stability and, when a special study of this property is required, the methods of investigating it must be selected according to the nature of the chemical under consideration. For example, sludging, an objectionable property of some oils, may be measured through laboratory tests (*19*).

Penetrability

Preservatives must penetrate wood satisfactorily in order to be acceptable. It is not reasonable to expect deep penetration by mere brushing, or brief immersion, although it would be fortunate if this were the case. Good penetration by such methods is frequently claimed for new preservatives, but, so far as is known, it has not been successfully attained. New preservatives, however, should penetrate as satisfactorily as those in common use, when applied by pressure or by other suitable methods. The protected zone must be deep enough so that it is not easily broken through in handling or by the ordinary wear and season checking to which wood is normally exposed in service.

Accurate comparisons of the penetrating properties of different preservatives are difficult to make because of the great variability of wood in resistance to penetration. Even in different parts of one face of a piece of wood, the penetration frequently varies by several hundred percent. There are also wide differences in penetration in different direc-

tions of the grain. End or longitudinal penetration, for example, usually averages more than 5 times the side penetration and sometimes is as much as 50 times as great. End penetrations of 15 to 20 times the side penetration are common. There is also a difference between side penetration across the annual rings (radial penetration) and side penetration parallel to the annual rings (tangential penetration), the tangential penetration being greater in most species. Penetration usually is very much greater in sapwood than in heartwood although there are exceptions to the rule.

For the foregoing reasons, specimens selected for comparative penetration tests should be either all sapwood or all heartwood, long enough to avoid complete penetration from the ends, and of large enough cross section to allow separate measurement of radial and tangential penetration. They should also be closely matched so as to be as nearly alike as possible in density, rate of growth, direction of grain, and other characteristics that may influence penetration. When practicable, it is desirable to make the specimens square in cross section, with two sides showing edge grain and two sides showing flat grain. Many experimenters and promoters of new preservatives have deceived themselves and others by failing to observe the above precautions. Salesmen also, by selection of easily penetrable wood and dependence upon end penetration alone, sometimes induce prospective customers to believe that their product has remarkable penetrating properties.

It is possible, with materials that are colored or can be made to give color reactions, to make rough comparisons and to learn whether the new material is significantly different in this respect from those in common use (*2, 4*). The depth of penetration of creosote and other colored oils is easily distinguishable upon cutting into or splitting open the treated wood. Copper sulphate and certain other salts also have sufficient color to be seen. Zinc chloride and sodium fluoride are examples of preservatives that are colorless, but whose presence can be made visible by spraying the treated surfaces with chemicals that produce colored compounds when they react with the preservative, or that are colored themselves, but are changed in color by reaction with the preservative in the treated parts of the wood.

With colorless preservatives for which no color tests have been devised, it is difficult to obtain even a good approximation of the depth to which they have penetrated. The addition of dyes to colorless solutions may not give accurate indications of penetration because the dyes sometimes filter out or fail to penetrate as far as the preservative.

The penetration of a preservative can be determined by quantitative chemical analyses of sections taken from a piece of treated wood by beginning at the surface and working toward the center of the piece. Such determinations are useful for showing the distribution of preservative in the wood but are much more costly than other methods for determining depth of penetration. The addition of radioactive isotopes to treating solutions is being studied as a means for quickly determining the penetration and distribution of preservatives in wood (*5*). The similar use of fluorescent materials has received some attention and merits further investigation.

A rough indication of the probability of good penetration can be obtained, for materials that do not react with the wood, by a consideration of their viscosities for, other things being equal, lower viscosities favor deeper penetration.

Safety in Use

A preservative must not involve a hazard to those handling either the preservative or the treated wood. Wood preservatives are, by nature, toxic materials, but with ordinary precautions their use should not involve a danger of poisoning. They should also be free from danger of fire or explosion. With suitable precautions they must not cause injury to persons, animals and plants with which they come in contact.

The fire and explosion hazard of the preservative during its preparation and storage, and during the treatment and the subsequent handling of the freshly treated wood can usually be determined sufficiently from the composition of the preservative. Water solutions of inorganic salts, of course, usually present no fire or explosion hazards. Oils and the common organic solvents have fire and explosion hazards more or less in proportion to their volatility. There are some solvents, of course, particularly those containing a high proportion of chlorine, that are volatile, but do not burn readily, if at all.

Usually the character of the material will give some information as to the probable health hazards connected with its preparation, handling, and use, for long experience in the industrial use of chemicals of various kinds has furnished much informa tion of this character. The possible toxic effects of a wood preservative to humans and animals are sometimes indicated through laboratory toxicological tests on animals. Such tests help to show the extent to which various quantities of chemicals, in the form of a dust, vapor or liquid, may be swallowed, inhaled, or absorbed through the skin without harmful effects. Patch tests on humans are useful for showing if preservatives are likely to cause skin irritations. Tests for determining potential health hazards should, of course, be made by competent specialists in this field.

Effects on Wood and Metal

Preservatives that attack wood and seriously reduce its strength are obviously unsuitable for prolonging its life. Corrosiveness to metal is also undesirable for corrosive preservatives damage the treating apparatus as well as bolts, nails, and other metal with which the treated wood must be in contact when in use.

Wood is resistant to attack by most chemicals and is seldom damaged by preservatives. Strong acids

and alkalis destroy it in time and certain other chemicals, in concentrated solution attack it. The probability of attack by a new preservative can usually be determined from its chemical composition. When tests are necessary, they may be very time consuming and expensive and may have to include comparative strength tests on treated and untreated specimens. In the case of plywood, tests have been made to determine the possible effects of preservatives on glue joints (*15*).

Comparative corrosiveness to metal can be measured by hanging strips of metal in containers of the various preservative solutions maintained at constant temperature, and noting their loss in weight from time to time (*24*). In such a test the results are influenced according to whether the metal strips are partially, alternately or completely immersed. Another method is to drive nails or screws, made of the various metals, into treated wood, expose the wood to different moisture and temperature conditions, and then measure the amount of deterioration of the metal by noting the loss in weight, the depth of corrosion, or the loss in strength (*10*).

Fire Retardance

Some wood preservatives have been developed for use in mines and other installations where combined protection against fire and decay is desired. Promoters of ordinary wood preservatives often claim fire resistance as one of the attributes of their products. The extent to which a preservative changes the resistance of wood to the spread of fire can be evaluated by several small scale test methods the following of which are the more commonly recognized (*1, 29, 32*):

(a) Fire-tube test (A.S.T.M. E69–47)
(b) Crib test (A.S.T.M. E160–46)
(c) Vertical flame spread (modified Schlyter) test
(d) Horizontal flame spread test (Federal Specification SS-A-118a)

These tests indicate any marked change from the performance of normal untreated wood. They do not, however, reveal directly the ease of ignition of the treated wood or its resistance to charring through or "heat penetration" upon continued exposure to flame or high temperatures. No method for determining ease of ignition has as yet been standardized. Resistance to fire penetration can be compared by placing test specimens over a standard flame or over the opening of a furnace maintained at a definite temperature or temperature range, and observing the time required for the temperature of the outer face to rise a given number of degrees above its original temperature, or for flame to show through. The time-temperature curve of A.S.T.M. Standard E119–47 (*1*) can be used for small-scale fire-resistance tests.

These small-scale tests give very useful indications as to how the treated wood compares with the untreated and they usually are sufficient. When the necessary apparatus is available, the tests need not be very expensive unless conducted on an elaborate scale. If more conclusive evidence is required, it may be necessary to build complete structural units of treated and untreated wood and have them tested by larger, standard fire tests, which are comparatively expensive. Recognized larger scale tests are A.S.T.M. E119–47, Standard methods of fire tests of building construction and materials (*1*), and Underwriters' Laboratories, Inc. fire hazard classification test of building materials (*38*).

Paintability

Painting properties of wood after treatment with a wood preservative may be impaired in one or more of four different ways. Oil-borne preservatives that may bleed from the wood, particularly when warmed or exposed to sunshine, may penetrate through the paint coating to discolor it or dislodge the coating in the form of blisters. Preservatives that contain colored substances soluble in the oils of paint may stain the coating. Some preservatives may retard the drying of paints. Still other preservatives may have an adverse effect on the life of paint even if they do not bleed or stain.

Coal-tar creosotes and similar oils may cause difficulty in any one of the three ways mentioned above (*21*), though creosoted wood that has been exposed to the weather for many months may eventually become paintable. If so treated that there is no serious bleeding, however, creosoted wood may be painted with aluminum paint to present a bright surface because the flakes of aluminum float on top of such coatings and hide the staining of the paint vehicle. White paint applied over aluminum paint may nevertheless become stained. On creosoted wood with rough surfaces such as sawed surfaces it is often possible to get a reasonably durable white coating by applying a water-thinned paint such as exterior casein paint or resin-emulsion paint.

Oil-soluble preservatives with little or no color, such as pentachlorophenol and zinc naphthenate, do not themselves affect paint but the oils in which they may be carried may do so unless they are volatile enough to escape before the painting is done. Strongly colored preservatives soluble in oil, such as copper naphthenate, may stain paint unless the preservative is made with ingredients that fix the preservative against spreading into the coating. Water-repellent preservatives that contain wax may retard or prevent the drying of finishes unless they contain effective fixatives for the wax.

Water-soluble preservatives such as zinc chloride do not stain or bleed through paint but they may impair the durability of the coating (*16*). Any preservative that discolors wood will, of course, seriously limit its usefulness for transparent finishes.

Tests on the staining of paint can be made by applying paint to treated wood, in sawed and round forms, and observing the extent to which discoloration occurs. Staining usually develops fairly quickly; if it does not appear within a few weeks it is not

likely to occur later. Tests for bleeding may be made in similar fashion except that the specimens should be exposed outdoors to full sunshine or other source of heat likely to be encountered in service and the observations should be continued for at least one full summer season.

Testing paints for durability on treated wood requires much more elaborate procedure and longer time of observation. Matched specimens of wood with and without treatment should be carefully and uniformly painted with the kinds of paint that will be used in service. A sufficient number of samples given identical preparation are necessary to average out individual variations. The test specimens should be suitably mounted on a test fence or other appropriate structure with the painted faces toward the south, preferably in a vertical position. Observations must be continued until the paint coatings wear out. Details of suitable testing procedures are described in other publications (*16 17*).

Tests of the effect of preservatives on the drying of coatings should be made on matched specimens of treated and untreated wood, painted simultaneously and uniformly, and allowed to dry side by side under the same atmospheric conditions. Methods are described in detail elsewhere (*18*).

Water Repellence

Water repellence is imparted to wood by oily or waxy materials, particularly by hydrocarbon waxes such as paraffin. Materials that remain as water-soluble substances in the wood are not water repellent. Water-repellents retard changes in moisture content and in dimensions of wood but they do not prevent such changes or alter the equilibrium to which wood will come if kept long enough under constant conditions. They greatly reduce changes in wood exposed to rapidly alternating extremes of dampness or dryness or exposed briefly to extreme conditions with longer intervals at average conditions. They are particularly effective against brief soaking by water because untreated wood absorbs free water rapidly. The effectiveness of treatment with a water repellent diminishes as the length of exposure to extreme conditions increases and becomes negligible for long intervals of exposure to extremes (*34*).

Special Tests

Some properties, such as color and odor, usually do not require formal tests for they can be readily observed. The tendency of the preservative solution to swell wood can usually be deduced from the composition of the solution, but can easily be tested by noting whether swelling takes place when wood is treated. Tests for other special properties, if required, must be devised according to the specific requirements to be met and the general character of the material under test.

Biological Assays

All of the above mentioned properties might be satisfactory but toxicity is required of all good preservatives in order to make the wood poisonous to the various organisms that might damage it. It seems possible for preservatives to repel some insects and marine borers without being toxic, but for general effectiveness, and especially for protection against fungi, toxicity is necessary.

During the last fifty years many investigators have determined the toxicity of chemicals by studying their effect when mixed with an artificial culture medium. For about twenty-five years attempts have been made to use wood or a wood product for this purpose.

Malt-agar tests.—In 1915 an attempt was made to standardize such tests (*26*). Their chief advantages are low cost and the relatively short time required for completion. In the United States the malt-agar method is most commonly used for determining toxicity of wood preservatives. It consists of growing a test fungus on malt-agar culture media containing different concentrations of the preservative under test (*37*). With nonvolatile materials, Petri dishes may be used as containers, but, when it is desired to reduce moisture losses during the test, or to prevent evaporation and loss of volatile materials, closed Erlenmeyer flasks may be employed. After the culture media containing the different concentrations of preservative have been prepared and poured into the Petri dishes or flasks, a small square of healthy mycelium cut from a specially grown culture is planted in each container. At sufficiently low concentrations, the fungus will grow and spread out over the culture medium while at higher concentrations the fungus transplant may be killed by the preservative. An intermediate concentration may be found at which the fungus will not grow, but at which it is not killed. This is called the *total inhibition* point. The lowest concentration at which the fungus is killed is called the *killing* point. These two values are expressed as percentages of the concentration of the preservative in the culture medium. In working with a new preservative, it is often desirable to use rather wide variations in concentration in a preliminary test to locate the killing point approximately, and then to determine it more accurately, using smaller variations in concentration in the vicinity of the approximate killing point. Since each set of determinations requires a month or more, a complete series of tests may extend over several months.

The killing point values obtained vary considerably with different species of fungi (*36*). For a preliminary survey, it is often sufficient to use one fungus, but in any comprehensive study, several species should be employed. When using only one fungus in the agar-plate toxicity test, the Forest Products Laboratory usually employs a special strain of a fungus known as Madison No. 517, which grows well in the laboratory and has been found very suitable for the purpose because it is highly resistant to many chemicals.

Baechler (*7*) has described a procedure for artificially aging creosote by bubbling air through the preservative and then testing by the agar-flask method. This procedure may furnish a means for estimating the permanence of preservative oils as well as their toxicity.

The results of toxicity tests must be used with caution. Differences in toxicity are too frequently assumed to be a direct measure of the relative effectiveness of preservatives, or to indicate the exact quantity required per cubic foot of wood to afford protection, neither of which is correct. Other properties, especially permanence, are of equal or greater importance. The most toxic preservative is valueless without sufficient permanence and comparatively low toxicity may be acceptable if permanence, cost, and other properties are favorable. Very high toxicity, when other properties are also favorable, indicates the possibility that low concentrations of the toxicant in the preservative solution, or low net retentions of the preserving compound, may be sufficient. It is not safe to risk the protection of important structures or products upon this assumption, however, until its correctness has been demonstrated by field experiments and service records.

Wood-block tests.—Many investigators prefer to make toxicity tests by treating wood blocks with different retentions of the preservative under test and then placing them in flasks on mats of fungus growing vigorously on a nutrient medium in Kolle flasks. Untreated wood is placed in each flask with the treated wood, or in separate flasks, for comparative purposes. This so-called European standard block test method was adopted at a conference held in Berlin in 1930 (*28*). As in the agar-plate method it is desirable to use several species of fungi. The exposure is usually continued for 3 or 4 months after which the blocks are removed, examined for evidence of decay, then dried and weighed. The amount of deterioration of the wood, as indicated by loss in weight and strength, and the concentration of the preservative required to prevent growth of the fungus, afford bases for comparing preservatives.

A block test for preservative oils intended for the treatment of sash and millwork has been standardized (*33*).

Soil-block method.—Investigators have sought to improve the block test procedure. Leutritz (*27*) introduced into the United States a soil-block technique that has been widely used. This test involves setting ¾-inch cube test blocks on feeder blocks on sterilized garden top soil in metal capped glass bottles. The properly wetted soil has been found to provide moisture in amounts necessary for good development of the test fungi. Duncan and Richards (*20*) have modified the soil-block method to include weathering of the treated blocks and in so doing have developed a measure of permanence as well as toxicity. The ¾-inch cube test blocks of longleaf pine sapwood are conditioned to equilibrium moisture content at 80° F. and 30 percent relative humidity, weighed and then treated with a range of retentions of the preservative under test. The blocks are then exposed, with or without weathering, to two or more test fungi after they have again come to equilibrium moisture content in the conditioning room. Fungi that are known to destroy the product to be protected are selected on the basis of their known degree of inhibition by the type of preservative to be tested. The weathering consists of hanging the treated blocks strung on nylon thread freely exposed to the weather for a period of 60 days and conditioning at 30 percent relative humidity for 3 weeks, after which they are weighed.

In the meantime vigorous cultures of the test fungi have been prepared in square 8-ounce bottles with metal screw tops. About 100 grams of soil (Miami silt loam, with pH of 5.6 to 6.0) are placed in each bottle with enough water to bring the moisture content of the soil up to 40 percent. Two longleaf pine sapwood feeder blocks (3.5 by 2 by 0.4 cm.) are placed on top of the soil side by side. The bottles are then loosely capped and autoclaved for 30 minutes at fifteen pounds pressure. When cool the feeder blocks are inoculated with the test fungus. These bottles are incubated at 80° F. and 70 percent relative humidity during the three weeks conditioning period for the test blocks.

One or two treated blocks of approximately the same retention are placed in each bottle on the feeder blocks, in such a way that they do not touch each other or the sides of the test bottle. The untreated control blocks are placed in similar culture jars.

The bottles containing the test blocks are then placed in a room with a constant temperature of 80° F. and 70 percent relative humidity for 12 weeks. At the end of this time the blocks are removed from the culture bottles, and the fungus brushed off. The blocks are then reconditioned to constant weight at 80° F. and 30 percent relative humidity and the final weights taken. These weights, and those obtained immediately prior to placing the blocks in the culture bottles, are used in computing the loss in weight due to decay.

In evaluating the results of the test or in determining the retentions where decay is present or absent, three criteria are applied if possible. First the blocks are carefully examined for visible decay. Second, the percentage losses in weight of the blocks over those that occurred in conditioning or weathering are determined. Either of these procedures when used alone may lead to the establishing of a threshold that is too high because it is based on the results of one or two blocks. A third method, strictly objective, makes use of a series of retentions above and below the anticipated threshold and establishes a threshold by using the results of all the blocks. In this the weight loss of each block is plotted against the pounds per cubic foot of preservative in

the block at the time of treatment. By projecting a straight line through those weight losses due to visible decay and one through those due to a loss in chemicals, the two lines intersect. The point of intersection indicates the threshold or the highest retention that might be expected to permit any decay.

In order to use such a graphic method of establishing the amount of preservative required to protect the wood it is necessary to treat blocks with a wide range of retentions rather closely spaced.

This soil-block test is more costly and requires a longer time to complete than malt-agar tests. It is not perfect but it has the advantage of using wood, the material the preservative is intended to protect and no artificial nutrient is used. It is felt that the soil-block test shows promise of giving results that may be correlated with the results of accelerated field tests.

Accelerated Field Tests

In accelerated field tests stakes of small cross section are used. They have a large ratio of surface area to unit volume which favors a more rapid loss of preservative through leaching, vaporization and chemical change than occurs in full-size wood products. The stakes used in accelerated tests are made up entirely of sapwood of an easily penetrated wood such as southern yellow pine. In this way the preservative penetration is generally good, although preservative distribution is different than in the case of full-size timbers which often contain a high proportion of heartwood and are not completely penetrated with the preservative. The range of preservative retentions is often narrower in a given treatment of test stakes than in full-size wood products. This, plus more uniform conditions of exposure, lead to good uniformity of results in accelerated field tests.

Stakes in accelerated tests are installed in plots, the location of which can be and should be selected to cover a wide variety of soil and climatic conditions and thereby be closely representative of actual service conditions. Test stakes for evaluating preservatives vary in size although the sizes in general use in the United States are either ¾ by ¾ inches or 2 by 4 inches (nominal) in cross section. The stakes are generally cut at least 18 inches long and are set upright in the ground to a depth of approximately 9 inches. The stakes are set from one to three feet apart in the plots, usually by a system of randomization. The stakes of smaller size require less material and furnish quicker results than the 2 by 4 stakes. The larger stakes, however, are less subject to loss and to breakage during removal and replacement for inspection, and their greater surface area offers a better opportunity for inspection without injury through picking. They also more closely approach the size of wood products used in construction than the smaller specimens do.

A standard method for accelerated tests with ¾-inch stakes has been approved by the American Wood-Preservers' Association and steps are being taken by that organization for the development of a standard on 2- by 4-inch stake tests (*23*). The details of the procedure used by the Forest Products Laboratory in tests on 2- by 4-inch stakes and the results of the tests have been reported by Blew (*14*).

Since colonies of termites are difficult to handle in the laboratory, field stake tests are more useful than laboratory tests for evaluating preservatives against termites.

Preservatives intended for marine use have been evaluated in accelerated tests using either short pile sections or small wood panels of various sizes (*23 31*).

Since the final criterion for evaluating preservatives is the result they give in actual use, those that show up well in the accelerated field tests should still be put to the test of actual use in full-sized timbers in service.

Service Tests

Service tests consist of a systematic study of the performance of full-sized products properly identified and installed under conditions of actual use. This includes exposure to natural conditions which include: irregular periods of wetting and drying, freezing and thawing, and sunlight, and should include normal soil or water conditions with the fungi and insects or marine organisms as they are present. The products in test should be of normal size since in specimens of reduced size the surface area exposed per unit of volume is proportionately greater, thus increasing the rate of leaching and weathering. The distribution of preservative, furthermore, is generally different in small specimens than in those of normal size and form.

Service tests should not be confined to one particular location since they are of most value and have greater application when installed in different localities under a variety of soil, water, and climatic conditions. For comparison the tests should include untreated along with treated products, or products treated with older or better known preservatives.

The service tests that are most useful are those that are carefully planned in advance. A description of the materials (wood products and preservatives) and treating procedures used, and systematic records on the installation and periodic inspections of the test material are highly important features of a service test. When it is practicable to do so it is desirable to determine and record the preservative retention on the individual pieces in the test. Reports of serviceability based on memory without a background of complete and accurate records are not reliable.

Service tests may be used to compare preservative treatments as well as preservatives. When designed expressly for the purpose of making comparisons of various preservatives and of different retentions of the same preservative, however, the treatment should be uniformly good and variables as to species

and characteristics of the wood, such as size, density and proportion of sapwood should be carefully controlled.

Much has been published on the subject of service test procedures and results. Angier (*6*) in 1911 reported on early service tests and discussed the subject of keeping better records of service tests on crossties. Since that year various committee reports and papers have been included in the annual Proceedings of the American Wood-Preservers' Association, showing the results of service tests on crossties, poles, piling (marine), posts, lumber and other treated products. Blew has suggested a procedure for service tests on posts as a means of evaluating wood preservatives and treatments (*12*) and reported on the results of a post test designed for comparing wood preservatives (*13*). Richards (*35*) proposed a form for reporting service records and a special form has been developed by the Forest Products Laboratory for users to report on the serviceability of treated structures. MacLean (*30*) has developed, on the basis of service records on 127,000 treated and untreated crossties, a chart for determining probable life of railroad ties. This chart is useful for predicting or estimating the average life of crossties after 10 percent or more of a group has been replaced. It has also been applied to other products such as poles, posts, and accelerated test stakes although the degree of accuracy with such products has not yet been fully determined.

Attention has been called earlier to the time factor as one of the principal limitations of service tests. The user of service records on treated wood products is cautioned against placing undue emphasis on tests involving a limited number of items and a single installation. Furthermore, the application of the results should not be made to conditions differing substantially from those used in the test. It does not follow that treated poles installed in the warm, moist areas of the South will perform as well as poles similarly treated and installed in the dry Rocky Mountain states or that crossties, which are subject to severe mechanical wear, will perform as well as similarly treated fence posts even though both are installed in the same area. Premature failures can often be explained by the treating conditions used and a preservative should not be condemned on the basis of a single failure. In other words, service tests are the best means for evaluating a preservative but they must be interpreted with care to avoid misuse.

Conclusions

While laboratory and accelerated field tests are useful for evaluating preservatives they do not adequately take into consideration the combination of exposure conditions surrounding wood in service. These tests cannot therefore be considered as a substitute for the more time-consuming service tests.

Precautions should be taken in all tests conducted on wood preservatives and treated wood, to see that the test specimens and their method of preparation are such that they give representative results. Abnormal retentions, for example, should be avoided unless the character of the test makes them necessary. Preservatives promoted for superficial application only should not, ordinarily, be applied to the test specimens by more thorough methods. The size and shape of the test specimens should receive careful consideration so that excessive end penetration does not lead to misleading conclusions. Retentions used in durability and permanence tests should be chosen with consideration for the retentions used or recommended for commercial practice. The number of test specimens should be sufficient to give dependable averages and, in all other ways, every care should be taken to avoid reliance upon nonrepresentative material or inadequate tests.

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The Chemical Composition of Eight Tropical Woods as Indicated by Proximate Analysis

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Composite samples of the following tropical woods were submitted to quantitative analyses: ***Tabebuia guayacan, Pseudosamanea guachapele, Ocotea rubra, Manilkara bidentata*** (from Puerto Rico), ***Manilkara bidentata*** (from Surinam), ***Cordia alliodora, Hymenaea courbaril***, and ***Licaria cayennensis***. These woods were specimens previously tested physically at the Yale School of Forestry and the present project was an orienting study undertaken to supplement physical studies at Yale with chemical data. The analytical data including extractives, ash, nitrogen, acetyl, uronic acid, xylan, tannin, lignin, methoxyl, hemicelluloses and alpha-cellulose, following a series of studies to determine the best conditions for such analyses.

Scope of the Project

STUDIES on the physical properties of tropical woods made for the Office of Naval Research by the School of Forestry, Yale University, gave rise to the present project. Seven wood species which had proved of special interest from the standpoint of physical properties and durability were suggested by the Yale School of Forestry for an orienting study on chemical composition by The Institute of Paper Chemistry. It is known that certain characteristics of a wood (such as color, surface properties, and resistance to insect and fungal attack), as well as their utilization, are often correlated with the presence of certain chemical components. In the present investigation, following careful comminution and sampling and some qualitative tests, a series of analyses were carried out, applying the most satisfactory known methods of *quantitative proximate analysis*. In a number of cases, a study of possible modifications in the analytical procedures usually used were made so as to meet the requirements of a specific tropical wood. Thus, a number of analyses were purely exploratory and reference to such orienting studies will be made in appropriate sections of the report.

The data obtained permitted satisfactory quantitative *summations* for the entire wood sample (within the limits of the precision of the methods). An over-all picture of the wood composition is thus given, which shows clearly the gross differences existing not only between the various tropical species but between these woods and some of our common native hardwoods. The analyses included qualitative tests for the sugar units present in the polysaccharides of each wood, for tannins, ether-solubles and certain coloring matter, and for steam volatiles. The typical "Maüle" color test for hardwood lignin was also carried out. Following these, quantitative analyses were made for: (a) ash, (b) nitrogen, (c) uronic anhydride content, (d) acetyl content, (e) pentosans (calculated as xylan corrected for uronic anhydride), (f) ether-soluble matter, (g) extractives soluble in cold 50 percent ethanol, (h) alcohol-benzene soluble matter, (i) hot water extractives, (j) tannin content, (k) methoxyl contents of unextracted and of extractive-free wood, (l) "Klason" lignin content (and percentage methoxyl in these lignins), (m) methoxyl not in lignin or extractives—"CH_2" values, (n) alpha-cellulose (corrected for ash and lignin and for residual uronic anhydride and xylan), and (o) hemicelluloses content. Finally, two series of summations were made.

Materials Used for Study

The wood samples received from the Yale School of Forestry, early in September, 1949, were representative specimens taken from the same timbers that had been tested previously in the Yale laboratories for the Office of Naval Research. The sample numbers given by the Yale School of Forestry to individual logs have been retained and are given *in brackets*. The following woods were obtained:

(I) *Tabebuia guayacan* ("Guayacan") (representing 3 logs from trees grown in Honduras) [82, 83 and 84]

(II) *Pseudosamanea guachapele* ("Frijolillo") (representing 3 logs from trees grown in Honduras) [79, 80 and 81]

(III) *Ocotea rubra* ("Determa") (representing 2 logs from trees grown in Surinam) [241 and 249]

(IV) *Manilkara bidentata* ("Bulletwood") (representing 3 logs from trees grown in Puerto Rico) [161, 162 and 163]

(V) *Manilkara bidentata* (representing 1 log from a tree grown in Surinam) [242]

(VI) *Cordia alliodora* ("Laurel Blanco") (representing 3 logs from trees grown in Honduras) [85, 86 and 320]

(VII) *Hymenaea courbaril* ("Courbaril") (representing 2 logs from trees grown in Honduras) [103 and 104]

(VIII) *Licaria cayennensis* ("Kaneelhart") (representing 1 log from a tree grown in Surinam) [243]

The test material was received in the form of small blocks (either rectangular or irregular in shape) cut from logs in the manner indicated on page 5 and Fig. 2 of the article by Dickinson, Hess and Wangaard (6). The specimen blocks were air dry and through the courtesy of Professor Wangaard, the sapwood and heartwood were clearly marked and could be differentiated readily. Soon after receipt, each block was measured and weighed and the relative amounts of heartwood and sapwood were estimated. Such estimates were only approxi-

mate because of numerous irregularly shaped specimens.

Preparation of Samples for Analysis

In no case were attempts made to comminute or to analyze heartwood and sapwood separately. The wood samples were reduced to meal, using first a circular saw and finally a Wiley mill. Small samples of the original wood blocks were also retained. After sawing, the meal was screened and that passing a 40-mesh screen and retained by a 60-mesh screen was kept separately from the finer portions (passing 60 mesh). The coarser wood particles (i.e., those larger than 40 mesh) were then passed through the Wiley mill, and again 40–60-mesh particles and "fines" were prepared. In this way, two main samples for each specimen were obtained. At all times, care was exercised to prevent overheating at the cutting surfaces.

In the case of each individual specimen approximately 5 percent of the total 40–60-mesh sample and 5 percent of the total "fines" were bottled and retained separately. The residual 95 percent of the 40–60-mesh samples of a specific species were uniformly mixed and the residual (95 percent) fines of this same species were also uniformly mixed to give composite samples.

A specific example should serve to make this clear. In the case of the specimens of wood from *Tabebuia guayacan,* the respective weights of the 40–60-mesh screened samples (from Nos. 82, 83, and 84) were 625.9, 521.3, and 558 grams. The respective weights of the "fines" were 687.3, 662.1, and 663.8 grams. The amounts of 40–60-mesh samples used for preparing the analytical samples were 594, 495.3, and 530.4 grams; these were thoroughly mixed to form a representative composite 40–60-mesh sample for *Tabebuia* (i.e., for the 3 logs Nos. 82, 83 and 84). Similarly the weights of the three "fines" which were separately mixed were, respectively, 652.3, 629.1, and 630.8 grams. Thus, for each species, *two* large representative composite samples were prepared.

One exception should be mentioned. The three samples from *Manilkara bidentata* from Puerto Rico (Nos. 161, 162, and 163) were mixed but kept separate from the one sample (No. 242) of this same species grown in Surinam. These woods from the two different countries were in all cases separately sampled and analyzed.

Whenever analyses could be made on mixtures of a 40–60-mesh sample and of fines, the composite 40–60-mesh specimen was mixed with the appropriate composite fines in a proportion which would be approximately representative of the entire wood. For example, in the case of *Tabebuia* (mentioned above), such a completely mixed sample (for Nos. 82, 83 and 84) contained 77 grams of the 40–60-mesh material and 92 grams of fines. The various wood samples were stored in appropriately sized, well-sealed Mason jars, or in smaller wide-mouth, screw-capped bottles. Moisture determinations (made by heating weighed samples to constant weight at 105° C.) were made concomitantly with each analysis. Throughout the course of this study, moisture determinations showed only slight variations.

Whenever samples required *no* filtrations during the course of an analysis (e.g., in a uronic acid determination), composite mixed samples of 40–60-mesh material and fines were used.

It should be noted that in recording tabulated analytical data, the *Roman code numbers* given below will be used in place of the arabic numerals assigned to these woods previously. These *Roman* numerals refer in all cases to *composite samples.*

(I) *Tabebuia guayacan*
(II) *Pseudosamanea guachapele*
(III) *Ocotea rubra*
(IV) *Manilkara bidentata* (from Puerto Rico)
(V) *Manilkara bidentata* (from Surinam)
(VI) *Cordia alliodora*
(VII) *Hymenaea courbaril*
(VIII) *Licaria cayennensis*

Orienting Qualitative Experiments

(a) The Nature of Carbohydrates in Tropical Woods

Inasmuch as the cell wells of wood contain largely polysaccharidic components, the sugar units entering into such carbohydrates are of interest. With the newer methods of paper partition chromatography, these can now be identified rapidly, even when they occur in small amounts in wood hydrolyzates.

Two-gram wood samples, previously extracted with 50 percent alcohol and hot water, were hydrolyzed at room temperature with 72 percent sulfuric acid for several hours, diluted with water to bring the acid mixture to 3 percent concentration, and boiled for several hours under a reflux. In each case, the boiling suspension was neutralized cautiously with barium carbonate, filtered, the clear filtrate acidified very slightly with acetic acid, and concentrated to a thin sirup. This was treated with a large excess of alcohol to precipitate barium salts, filtered, and again evaporated to a sirup. Triturations with alcohol, filtrations, and evaporations were repeated until no further precipitation of alcohol-insoluble salts occurred. The final solution was then submitted to paper partition chromatographic analysis by the method of Wise, Green, and Rittenhouse (*23*). This technique had been found useful previously in showing the presence of specific sugars in complex mixtures, in the hydrolyzates of such mucilages as guar, arabogalactan, various alpha-celluloses, and kraft, soda, and sulfite pulps. The technique used was very similar to that described by Partridge (*20*).

Whatman No. 1 filter paper (the formation of which is satisfactory) was used as the stationary phase, the dimensions of the paper strips being 4 by 22 inches. The aqueous solutions usually con-

tained 1 percent (weight/volume) of each of several sugars. From 0.5 to 1.0 mg. of a solution was introduced as a circular spot on a horizontal line ruled about 8 cm. from the top of the paper strip. When a number of different solutions were to be tested, spots were kept about 0.5 cm. apart (measuring from the circumference of each spot). A mixture consisting of butanol 40 percent, ethanol 10 percent, and water 50 percent was prepared and, after removing the lower aqueous layer (L), the upper organic layer (solvent) was placed in a glass trough feeding the paper strip. The top edge of the strip carrying the sugars was then immersed in this solvent (about 4 cm. from the sugar spots) and the strip was allowed to hang vertically inside a closed vessel at the bottom of which was placed the aqueous layer (L) referred to above. The filter paper thus became rapidly saturated with vapor from phase (L). The temperature was maintained at 22 to 24° C. and the solvent was permitted to progress *downward* for about 16 to 20 hours (i.e., overnight). The lower solvent line was then marked off by a pencil line and the strip freed from solvent at 100° C. The solvent front usually advanced about 22 to 30 cm.

Depending on their configurations, the sugars migrate at different rates. After the solvent has been removed, the sugar spots are "fixed" by brushing evenly and swiftly with a water-saturated butanol solution of aniline acid phthalate and drying at 105° C. for 5 to 10 minutes. The relative positions of the sugars are shown by brown spots in the case of the hexoses and purplish or pink spots in the case of the pentose sugars. The partition of the solute takes place between water bound by the paper and the solvent moving over its surface. The distance which any sugar moves is a function of (a) its coefficient of partition between water and the wet solvent, (b) the volume of water bound by unit area of filter paper, and (c) the volume of wet solvent held by unit area of the paper after irrigation. The two latter factors are substantially constant (assuming that the paper is uniform in structure, water content, and caliper). Under ideal conditions, the relative distance (termed R_F) that is traversed by each sugar is dependent only on its partition coefficient.

$$R_F = \frac{\text{distance on the strip moved by the sugar}}{\text{distance moved by the advancing front of organic solvent}}$$

In these experiments, however, the R_F of a specific sugar was not determined. In its place, the sugar migrations were compared directly with known sugar solutions carried out on the same paper strip on which the unknown samples were chromatographed. For example, when a sample of hydrolyzed wood was subjected to partition chromatography, the results were compared directly with those given by pure glucose, mannose, and xylose solutions (or mixtures of these). In general, satisfactory results (and discrete spots) were obtained with sugar mixtures containing as many as four sugars. Less satisfactory results were obtained when uronic acids were also present but these were normally removed as barium salts by the alcohol precipitation referred to above. In each of the eight wood hydrolyzates, clear evidence was obtained for the presence of large amounts of glucose and xylose. As expected, these were the dominant sugars. However, there was also evidence that mannose was present in very subordinate amounts. This was confirmed in the case of each of the eight woods by the formation of the typical insoluble *mannose phenylhydrazone* (melting with decomposition at 193–200° C., depending on the purity of the sample). In no case did the amount of mannose warrant a quantitative determination, the accuracy of which (as experience has shown) leaves much to be desired. The fact, however, that small amounts of mannose residues were present in these angiosperms is in harmony with previous findings on other native woods [cf. Wise, Ratliff, and Browning (*24*)].

By using much larger samples of the eight woods and by employing far milder hydrolytic treatments, it was possible to explore the wood carbohydrates somewhat further. In this case, 25-gram samples, pre-extracted repeatedly with 50 percent alcohol and washed with cold water, were used. Hydrolyses with 0.01 *N* sulfuric acid over an eight-hour period gave a solution which, when neutralized, concentrated, and treated in the usual manner, and chromatographed, showed the typical pink *arabinose chromatogram* for each of the eight samples examined.

The woody residues remaining from these mild hydrolyses were in every case hydrolyzed further for eight hours, by refluxing with 0.1 *N* H_2SO_4. Chromatograms of these hydrolyzates showed not only the typical arabinose spots but xylose spots as well, evidences of an unidentified disaccharide, and slight traces of *galactose*. The solution used in these later chromatograms was 40 percent butanol, 10 percent glacial acetic, and 50 percent water.

Summarizing these chromatographic data, the purified wood hydrolyzates contained in decreasing order of magnitude the following components: D-glucose > D-xylose > D-mannose > L-arabinose > D-galactose. In no cases were quantitative determinations of arabinose or galactose warranted, and the amounts were too slight to obtain confirmation by the preparation of chemical derivatives.

(b) Qualitative Tests for Tannins

Approximately 0.5 gram of each air-dried wood meal "fines" was treated in a test tube with 4 cc. of water and heated 10 minutes in a boiling water bath. One drop of 4 percent HCl was added and the mixture treated with another 4 cc. of water and filtered. To 2.5 cc. of the filtrate was added 0.5 cc. of a standard gelatin solution (containing 1 percent gelatin and 10 percent sodium chloride). Precipi-

tation indicated the presence of tannins. The results are shown in Table 1.

TABLE 1.—QUALITATIVE TEST FOR TANNINS

Wood	Test for tannins
(I) *Tabebuia guayacan*	Negative
(II) *Pseudosamanea guachapele*	Negative
(V) *Manilkara bidentata* (Surinam)	Positive
(IV) *Manilkara bidentata* (Puerto Rico)	Positive
(III) *Ocotea rubra*	Negative
(VII) *Hymenaea courbaril*	Positive
(VI) *Cordia alliodora*	Negative
(VIII) *Licaria cayennensis*	Positive

In no cases were the tannin tests heavy.

(c) Qualitative Tests for Ether Solubility; Identification of Lapachol

Small wood samples were warmed with ether but only in the three following woods were appreciable amounts of ether extractives obtained: *Tabebuia guayacan, Pseudosamenea guachapele,* and *Ocotea rubra.* As a result, quantitative ether extractions were made only in the case of these woods and these data are given in a subsequent section.

The ether extract from *Tabebuia guayacan* was deep yellow. When this ether extract was shaken with dilute aqueous sodium carbonate, a portion of the coloring matter entered the aqueous layer giving a deep red solution. On acidification with hydrochloric acid, the alkaline solution yielded a yellow solid which was filtered and washed with water. The material, when recrystallized from aqueous alcohol, melted at 138–138.5° C. An authentic sample of lapachol, obtained through the courtesy of Dr. L. F. Fieser of Harvard University, melted at 138.5–139.3° C. The mixture melted at 138.5–139°,. thus indicating clearly that this coloring matter was *lapachol.* The presence of this pigment had been reported previously in *Tabebuia* (*15*). The yellow pigment remaining in the ether solution after alkaline extraction remains unidentified.

(d) Tests for Starch

Aqueous extracts of the eight woods were prepared by boiling small samples of the woods with water, followed by filtration. The cooled clear filtrate was in each case tested with a dilute aqueous solution of iodine in potassium iodide. A typical positive, deep blue coloration for starch-iodide was given by the following woods: *Hymenaea courbaril, Ocotea rubra, Cordia alliodora, Tabebuia guayacan* (slight), *Pseudosamanea guachepele.* The two samples of *Manilkara bidentata* and *Licaria cayennensis* did not show the presence of starch.

(e) Steam Volatiles

The woods of *Cordia alliodora* and *Licari cayennensis* had pleasant odors. That of *Ocotea rubra* showed a marked discrepancy between the amount of 50 percent alcohol-soluble extractives obtained by *direct weighing* and that found by *loss in weight* (cf. section on extractives). Steam-volatile substances were suspected, and 25-gram samples of each of these woods were distilled with steam. The *Cordia alliodora* gave a very small amount of volatile oil which, after extraction with ether and evaporation of the ether, left a brownish, viscous liquid (which had evidently lost some of the more volatile, odoriferous components). *Licaria* gave only very slight amounts of a volatile oil with a faint odor. *Ocotea rubra* also yielded some steam-volatile component which, however, appeared to be largely soluble in water. The steam distillate when extracted with ether, followed by evaporation of the ether, gave a nearly colorless, viscous oil in very small amounts. Neither of these three volatile components were investigated further, nor were any other woods subjected to steam distillation. Inasmuch as the extractive contents of these other woods determined by direct weight were seldom much lower than that determined by loss in weight, it was obvious that very little easily volatile material could have been present.

(f) The Modified Maüle Reaction (*17*) for Syringyl Groups

This reaction furnishes a chemical means of differentiating between the wood of angiosperms and that of gymnosperms. It depends on the presence of syringyl groups in the lignin of hardwoods, and their absence in that of the conifers. When shaken with chlorine water for a few minutes, followed by treatment with aqueous sodium sulfite, hardwoods give a brilliant cerise coloration; softwoods give a nondescript orange to brown color. All samples of tropical woods yielded the bright cherry-red coloration.

Ash Determinations

In all cases, composite samples representative of the entire wood were used. Thus, both coarse and fine particles were included in the sample. The weighed samples were charred very carefully so as to prevent flaming and then heated to constant weight in a muffle furnace at dark red heat (about 650–750° C.). The results (averages of duplicate or triplicate determinations) are given in Table 2.

TABLE 2.—ASH IN TROPICAL WOODS
(Unextracted, ovendry basis)

Wood	Ash percent
I	0.33
II	0.58
III	0.19
IV	0.695
V	0.365
VI	0.98
VII	0.85
VIII	0.025

With two exceptions, these values fall within the usual range of mineral components found in hardwoods native to the United States (*15*). That of VI (*Cordia alliodora*) is somewhat higher than usual. That of VIII (*Licaria cayennensis*) is far below that found in any of our native woods, and represents an ash content which is surprisingly low for any type of plant tissue.

Nitrogen Determinations

The original (unextracted) wood samples (using a mixture of fines and 40–60-mesh sawdust) were analyzed for nitrogen by Ma and Zuazaga's modification of a micro-Kjeldahl procedure (*16*). In the final phase of the determination, ammonia (formed during the digestion) was distilled into a 4 percent boric acid solution containing a mixture of Bromocresol green and Methyl red. The solution was then titrated with 0.05 *N* HCl to a definite pink. Controls were run on all reagents. Table 3 gives the duplicate (or triplicate) nitrogen values.

TABLE 3.—NITROGEN CONTENT OF TROPICAL WOODS

(Unextracted, ovendry basis)

Wood	Nitrogen percent
I	0.27, 0.28
II	0.27, 0.26, 0.24
III	0.08, 0.08
IV	0.07, 0.08
V	0.07, 0.06
VI	0.32, 0.31
VII	0.23, 0.21
VIII	0.20, 0.20, 0.18

With the possible exception of specimens I, II, and VI, these values fall within the usual range of our native hardwoods. Presumably the nitrogen in these woods is due principally to the proteins in the dried protoplasm. The presence of alkaloids is not excluded but no tests for these have been made.

The Uronic Anhydride Content

All woods contain uronic acids in polymerized form. These may be present either in the hemicelluloses or as pectic materials in the wood.

The method used for their determination was that of Browning (*5*). This depends on the principle that uronic acids or polyuronides, when distilled with 12 percent hydrochloric acid saturated with sodium chloride at 137–140° C., are quantitatively decarboxylated. Nitrogen is used to flush out the carbon dioxide, which is freed completely from simultaneously generated furfural, by passage through a trap containing phosphoric acid and silver phosphate. The carbon dioxide, after passing through a drying tube containing Anhydrone, is absorbed quantitatively in an absorption tube containing Ascarite (with an auxiliary layer of Anhydrone to absorb moisture). Suitable guard tubes are provided at either end of the train. The weight of carbon dioxide, multiplied by four, gives the weight of uronic acid. In general two-gram samples of wood (mixtures of fines and 40–60-mesh meal) were used. The results are given in Table 4.

The results, which are the averages of closely agreeing duplicate determinations, fall within the usual range found for native hardwoods (*2, 25*).

TABLE 4.—URONIC ANHYDRIDE CONTENT OF TROPICAL WOODS

(Unextracted, ovendry basis)

Wood	CO_2 percent	Uronic anhydride percent
I	1.205	4.82
II	1.20	4.80
III	0.95	3.80
IV	1.065	4.26
V	1.06	4.24
VI	1.46	5.84
VII	1.25	5.00
VIII	0.86	3.44

Acetyl Content

Woods invariably contain acyl groups which, on hydrolysis, are converted into volatile organic acids. Although small amounts of formic acid may be formed, acetic acid predominates, and the volatile acids content of a wood is usually reported as "acetic acid" or, more frequently, as "percentage acetyl." The method used in this determination is essentially that of Freudenberg and Harder (*10*). The acetyl groups are split off and immediately esterified with ethanol in the presence of *p*-toluenesulfonic acid. The ester (ethyl acetate) is distilled, caught quantitatively in a suitable receiving flask, and subsequently saponified with standard 0.2 *N* sodium hydroxide, the excess of which is back titrated with 0.2 *N* sulfuric acid.

Inasmuch as the original acetyl groups are associated largely with the polysaccharides of wood, it is believed that they are chemically bound to the wood hemicelluloses (presumably the xylans). Table 5 gives the acetyl values (on the basis of oven-dried, unextracted wood). With the exception of VII, these percentages, as compared with those of our native hardwoods, are quite low, those of III and VIII being unusually low. In contrast, two of the native oaks (*Quercus rubra* and *Q. lyrata*) analyzed at the Institute contained, respectively, 3.0 and 2.45 percent acetyl, and a sample of aspen (*Populus sp.*) contained 3.3 percent acetyl. Freeman and Peterson (*8*), who made summative analyses of aspen, beech, maple, birch, and fire cherry, reported acetyl values of 4.9 to 8.79 percent. Inasmuch as there is often a correlation between the acetyl content and the xylan content, low xylan values might well be expected in many of these woods. As indicated in another section, this is actually the case.

TABLE 5.—ACETYL CONTENT OF TROPICAL WOODS

(Unextracted, ovendry basis)

Wood	Acetyl percent
I	1.1
II	1.5
III	0.81
IV	1.3
V	1.1
VI	1.3
VII	2.2
VIII	0.76

Pentosans; Estimation of the Xylan Content

Preliminary chromatographic data indicated that all eight woods contained appreciable amounts of xylans and only subordinate amounts of arabans. Pentosans in each wood (containing a mixture of

fines and 40–60-mesh) were converted into furfural by distilling with 12 percent hydrochloric acid under standardized conditions. Furfural was then determined as the phloroglucide (*4*). From the weight of phloroglucide, the pentosan content was calculated by the use of Kröber's tables (*14*).

Inasmuch as uronic acids and polyuronides also yield a certain amount of furfural when distilled with hydrochloric acid under the conditions used in the pentosan determination, suitable correction should be made for this additional furfural. Any such correction, however, is only proximate. Empirical corrections were applied and the corrected *phloroglucide* values were then converted into the corresponding *xylan* values.

Corrected xylan values were arrived at by the following calculations. The weight of pentosans (in mg.) corresponding to 1 gram of ovendry wood was converted (by use of Kröber's tables) into the *corresponding weight* of *furfural phloroglucide.* This weight is termed (A). The weight of carbon dioxide (in mg.) generated in the uronic acid determination corresponding to one gram of ovendry wood was then multiplied by the empirical factor 1.47, giving (B), the corresponding number of milligrams of furfural phloroglucide from the furfural generated by the uronic acid groups in the wood. Then (A) minus (B) equals the *corrected* weight of furfural phloroglucide due to the pentosans alone. Table 6 contains both the uncorrected percentages of *pentosan,* and the corrected *xylan* values in the eight wood samples. It will be noted that these differences are significant.

TABLE 6.—UNCORRECTED PENTOSAN AND CORRECTED XYLAN CONTENT OF TROPICAL WOODS

(Unextracted, ovendry basis)

Wood	Pentosan percent	Xylan percent
I	16.15	13.2
II	17.3	14.3
III	14.15	11.7
IV	18.6	15.6
V	17.65	14.75
VI	17.55	14.2
VII	19.3	16.1
VIII	13.5	11.25

Kröber (*14*) *assumed* that the pentosans of plant tissues contained *equal* amounts of xylan and araban. This was a purely formal concept. Experience has shown that this is never true for woods and, hence, the corrected xylan figure is much more nearly correct than would be even a corrected pentosan value derived from Kröber's calculations. The small amount of arabinose units present in these woods should have but an insignificant effect on these xylan values.

With the possible exception of VII (*Hymenaea courbaril*), the tropical woods contained less pentosans than do most of our native angiosperms. (In very few cases have the corrected xylan calculations been made after a pentosan determination.) A few comparative pentosan data on native hardwoods (given on the ovendry basis) follow: quaking aspen 18.8 percent; big tooth aspen 23.3–23.7 percent; yellow birch 22.6–26.8 percent; paper birch 21.8–28.7 percent; American elm 16.2 percent; white ash 19.85–20.2 percent; white oak 21.7–23.25 percent; sugar maple 22.8 percent; basswood 16.6 percent. The data given above are taken largely from those furnished by the Forest Products Laboratory (*21*), together with a few analyses made by Freeman and Peterson (*8*).

Extractives

General Discussion

The term "extractives" refers to those components of a wood which can be removed by the use of neutral organic solvents or by water. Often extractives serve to characterize a wood (and sometimes a family or species). They are not parts of the cell wall. Extractives may impart a characteristic color, odor, resistance to insect or fungal attack, toxicity, flammability, etc. to a specific wood and they may influence the chemical or even physical utilization of a species.

Neutral solvents are incapable of removing *all* the noncellular components and certain amounts of extraneous materials undoubtedly remain trapped in the minute capillaries of the wood, even after what appears to be an exhaustive extraction. Thus, most woods are far from colorless even when thoroughly extracted. However, the amounts of such extraneous (unextractable) materials are usually relatively small and do not seriously vitiate a summative wood analysis. Nevertheless, their presence should not be discounted.

Extractives may be determined in one of two ways. The extract from a specific solvent may be dried and *weighed directly,* or it may be found by difference, by determining the loss in weight of a wood sample after extraction. (In the latter case, due account must also be taken of the moisture in the wood sample.) Both methods have been applied in the present study, and the over-all summations in Table 7 give total extractives, determined by either method.

Ether-Soluble Matter

In all quantitative extractions, 40–60-mesh wood samples were used. Only three woods (I, II, and III) were extracted with ether. These extractions were made in a Soxhlet extractor using approximately 5 grams (accurately weighed) air-dried wood. Extractions were continued until the ether extracts were colorless (or until they no longer yielded residues on evaporation). Ether extracts were evaporated to dryness carefully and then dried to constant weight at 60–70° C. The ether solubility was checked by weighing the air-dried wood residue remaining after extraction, determining the moisture content, and correcting for water. Thus, the ether extractives were determined both by *direct weight* and by *loss in weight* as indicated in Table

7. The two sets of determinations gave results that were nearly identical.

Cold 50 Percent Ethanol Extractives

The wood residues from the ether extractions (in the case of I, II and III) and the original 40–60-mesh wood samples (in all other cases) were submitted to extraction at room temperature with 50 percent alcohol. Five-gram samples in 150 ml. 50 percent ethanol were allowed to stand 24 hours at 27° C. with frequent shaking in a glass-stoppered Erlenmeyer flask. The contents of each flask was then decanted quantitatively through a glass Soxhlet thimble, and the flasks and residues washed with 50 percent alcohol. The wood residues were then air-dried, transferred quantitatively into the original Erlenmeyer flasks and re-extracted with fresh 50 percent alcohol. This filtered extract was added to the original filtrates. Similarly, 50 percent alcoholic extractions were continued until the extracts were practically colorless. The final wood residues were filtered, washed with ether, and again air dried. The combined extracts and washings were evaporated to dryness (finally in a suitable weighing bottle) and dried to constant weight at 60–70° C. In most instances, the direct weights were checked by determining the percentage loss in weight. As indicated in Table 7, only in the case of III (*Ocotea rubra*) and VI (*Cordia alliodora*) were results obtained by the two methods significantly different. Both of these woods contained steam-volatile materials, which were evidently lost when the alcohol-soluble extracts were evaporated to dryness.

Alcohol-Benzene Soluble Matter

The air-dried wood residues from the alcohol extractions were extracted in a Soxhlet with a mixture of 1 part of alcohol and 2 parts of benzene. As usual, the extract was evaporated to dryness and weighed. As indicated in Table 7, extractives obtained by the use of this solvent mixture were usually slight, indicating that the 50 percent alcohol had removed most of those extractives usually removed by alcohol-benzene. When the extraction was complete, the wood residues were washed with anhydrous ether and air dried. In only two instances were the extractives found by direct weighing checked by determining the corresponding loss in weight. In few of these determinations was it possible to obtain good precision and the results are highly proximate.

Hot Water Extractives

The wood residues from the alcohol-benzene extractions were transferred quantitatively to appropriate Erlenmeyer flasks provided with air condensers, and heated 1 hour on a steam bath with 200 ml. of boiling water. The solutions were filtered quantitatively and the residues retreated with hot water. The extractions were repeated until the water extracts were nearly colorless. All water extracts and washings were combined, evaporated to dryness, and dried to constant weight at 60–70° C. The wood residues were dried to constant weight at 100° C. From these final "extractive-free" wood residues it was possible to calculate the *total extractives* lost during the successive operations.

Table 7 gives a summary of the data on extractives. A comparison of the over-all results obtained by summation of the weighed dried extracts and by the total loss in weight is shown in the last two columns of the table. With the exceptions of woods III and VI, the agreement is satisfactory.

The ether extractives (although not examined further) may have included essential oils, resins, waxes, sterols, and fixed oils and certain coloring matters (like lapachol). The most interesting ether extract was that of III (*Ocotea rubra*) which was a partially crystalline waxy solid. The 50 percent alcoholic extracts contained tannins (when there were present) and coloring matters. The water solubles included starch, coloring matters, and possibly sugars and alkaloids. No investigations of these various fractions were made.

One of the surprising features of this series of analyses is that most of the woods under examination are not unusually high in total extractives. Direct comparison with our native hardwoods cannot be made readily because it is seldom that *successive* extractions have been made with a final summation, but it would appear that only *Pseudosamanea guachapele* and *Hymenaea courbaril* show an over-all extractive content higher than that found often in North American species. The analyses of

TABLE 7.—EXTRACTIVES IN TROPICAL WOODS DETERMINED BY DIRECT WEIGHT AND BY LOSS IN WEIGHT ON AIR DRIED (40–60-MESH) SAMPLES, COMPUTED ON THE OVENDRY BASIS

Wood	Ether Extract percent		Cold 50% EtOH Extract percent		Alcohol-benzene Extract percent		Hot Water Extract percent		Total Extractives percent	
	By Loss in Wt.	By Direct Weight	By Loss in Wt.	By Direct Weight	By Loss in Wt.	By Direct Weight	By Loss in Wt.	By Direct Weight	By Loss in Wt.	By Direct Weight
I	2.0[b]	1.95[a]	4.7[a]	4.8[a]	0.7[a]	0.65[a]	1.15[a]	0.7[a]	8.55	8.1
II	2.7[a]	2.6[a]	8.4[a]	8.25[a]	0.65[a]	0.53[a]	1.37[a]	1.33[a]	13.12	12.75
III	4.0[a]	4.1[a]	4.4[b]	3.04[b]	——	0.6[b]	——	0.97[a]	10.08	8.71
IV	——[d]	——	7.95[a]	7.4[a]	——	0.28[a]	——	1.08[a]	9.21	8.76
V	——	——	6.35[a]	6.1[a]	——	0.31[a]	——	1.0[a]	7.48	7.37
VI	——	——	5.25[c]	4.2[c]	——	0.38[c]	——	1.15[c]	6.55	5.73
VII	——	——	——	11.45[a]	——	0.68[a]	——	1.35[a]	13.75	13.43
VIII	——	——	——	6.85[a]	——	0.88[a]	——	2.24[a]	10.42	9.97

[a]Results of duplicate determinations.
[b]Results of triplicate determinations.
[c]Results of quadruplicate determinations.
[d]Dashes indicate that no determinations were made.

a few American oaks analyzed for total extractives tend to confirm the view. Thus *Quercus agrifolia* contained about 8 percent (7), Quercus rubra contained 9.8 percent and Quercus lyrata (both analyzed at The Institute of Paper Chemistry) yielded 12.8 percent total extractives. It is interesting to compare the extractive content of these woods with that of a sample of quebracho, which contained approximately 37.8 percent extractives (*26*). The extractive-free woods were used in subsequent lignin determinations and in certain of the methoxyl analyses.

Tannin Content

Tannins, among other phenolic extractives, probably enhance the durability of various tropical woods. Four of the tropical woods under investigation were shown to contain small amounts of tannin, which were determined quantitatively by the official method of the American Leather Chemists' Association (ALCA), which permits the determination of tannin fixed by hide powder under specified conditions (*1*). In this determination a water extraction of the original wood is made at about 100° C. and, in the case of these (low tannin) woods, the tannin content of this solution was about 1 gram per liter. The wet hide powder used was 18.5 grams. The usual ALCA method is designed for the analysis of raw materials containing 7–8 percent (or more) of tannin and is not well suited to samples containing only small amounts. The results, given in Table 8, were obtained by the procedure of the ALCA for the extraction and analyses of raw materials which are *low* in tannin. In conformity with the custom of the ALCA, the results are reported on the basis of *air-dried* (not oven-dried) wood. The water-soluble nontannins and the components that are insoluble (when the hot water extract cools to 23° C.) are also included in Table 8.

The tannin content of these woods is far below that which would make commercial extraction economically feasible. On the other hand, they may in part explain the durability of these species.

Methoxyl Content

Methoxyl groups are present in all woods. Most of these are due to substituent groups in the lignin, but appreciable amounts are also present as ether groupings of the uronic acid units of wood hemicelluloses and very small amounts may be present in some of the extractable components. Thus, methoxyl determinations are important from several points of view.

The determination is carried out by a modification and simplification of the original Zeisel procedure (*30*). Essentially, this involves the Vieböck and Schwappach method (*22*). The wood is heated with hydriodic acid (containing phenol) which converts the *methoxyl groups* into *methyl iodide*. The latter is absorbed in an acetic acid solution of potassium acetate containing bromine. The reaction is carried out in a special flask using a current of carbon dioxide. An intermediate scrubber traps any hydriodic acid or free iodine. The methyl iodide is converted by the bromine into iodine bromide, which in turn passes into iodic acid and hydrogen bromide. Any free bromine present is then destroyed by the addition of formic acid. The iodate is determined by the addition of potassium iodide and titration of the resulting free iodine by means of standard sodium thiosulfate. Thus *one* methoxyl group is equivalent to 3 *moles of iodine*, which thus furnishes an extremely favorable analytical factor.

The following reactions are involved in the determination:

$$ROCH_3 + HI \longrightarrow ROH + CH_3I$$
$$CH_3I + Br_2 \longrightarrow CH_3Br + IBr$$
$$IBr + 2Br_2 + 3H_2O \longrightarrow HIO_3 + 5HBr$$
$$HIO_3 + 5HI \longrightarrow 3I_2 + H_2O$$
$$3I_2 + 6Na_2S_2O_3 \longrightarrow 6NaI + 3Na_2S_4O_6$$

Methoxyl determinations were made in duplicate both on the original woods (using a mixed sample containing both 40–60 mesh and fines) and on extractive-free (40–60 mesh) samples. Results are given in Table 9.

TABLE 9.—METHOXYL CONTENT OF TROPICAL WOODS

(Unextracted, ovendry basis)

Wood	Methoxyl in Original Wood percent	Methoxyl in Extractive-free Wood percent
I	7.0	7.0
II	6.03	6.45
III	6.6	7.25
IV	6.5	6.85
V	7.45	7.7
VI	6.95	7.05
VII	5.4	5.4
VIII	6.3	6.45

TABLE 8.—TANNINS AND NONTANNINS IN TROPICAL WOODS

(Unextracted, airdry basis)

Wood	Tannins percent	Nontannins percent	Insolubles* percent	Ratio of tannin to total (hot water-soluble) extractives percent
Licaria cayennensis	2.7	3.4	0.5	40.9
Manilkara bidentata (Surinam)	2.0	3.6	0.2	34.5
Manilkara bidentata (Puerto Rico)	3.5	2.7	0.2	54.7
Hymenaea courbaril	4.3	5.1	1.1	41.0

*Soluble in hot but not in cold water.

The differences in the results for the extractive-free and the unextracted woods are not marked. They indicate that methoxyl-containing substances have been removed on extraction and/or that there are slight differences in the methoxyl content between the fines and the 40–60-mesh samples.

As indicated in the following section, methoxyl determinations were also made on isolated lignin fractions.

Lignin Contents

The "Klason" lignin determination as applied to the woods of angiosperms is often very unsatisfactory. It involves a drastic procedure. The extractive-free wood is treated with cold 72 percent sulfuric acid until disintegration takes place. The hydrolysis of the polysaccharides (cellulose and the hemicelluloses) is then completed by diluting the mixture with water (to 3 percent acid) and heating four hours at constant volume. The brown lignin residue is then filtered, washed, dried, and weighed. Certain carbohydrates, nitrogenous matters, and other materials may interfere with the determination and the "homogeneity" of the lignin is usually gaged by the methoxyl content of the residue which, in our North American hardwoods, usually ranges from about 20 to 21.5 percent.

Freudenberg and Ploetz (*11*) showed that 72 percent sulfuric acid was not necessarily the optimum for *all* hardwoods. Therefore, they treated extractive-free wood with sulfuric acid solutions of varying concentrations (both above and below 72 percent). The most probable lignin content was taken as that which gave the *highest* methoxyl value. When the acid strength was too low, the apparent lignin content was too high but the methoxyl content was correspondingly low. When the acid concentration was too high, degradation of the lignin sometimes occurred and the methoxyl value again dropped.

In the present study in an exploratory series of analyses, fully extracted wood samples were treated with 69 percent, 72 percent, and 75 percent sulfuric acid. The lignin yields were determined, and the methoxyl content of most of these fractions was also determined. In all instances, 72 percent sulfuric acid gave the most probable lignin values (although in the case of *Cordia alliodora,* 69 percent and 72 percent H_2SO gave identical values) and, in the case of *Ocotea rubra,* the respective yields of lignin (and corresponding methoxyl values) were also nearly identical. The lignin values given in Table 10 were corrected for sulfated ash (which was always very slight). The corresponding methoxyl values are also given in Table 10. In most instances, the effect on the lignin determination of changed acid concentrations was marked. This was especially true when 69 percent acid was used. *Manilkara bidentata* (from Puerto Rico) may be cited as an example. With 69 percent acid, the "apparent lignin" in the extractive-free wood was 53.2 percent (with 10.35 percent methoxyl). With 72 percent acid, the apparent lignin content was 26.8 percent (with 20.8 percent methoxyl), and with 75 percent acid the apparent lignin value was 27.3 percent (with 20.6 percent methoxyl). It is evident that the high "apparent lignin" obtained with 69 percent acid is spurious. Table 10 gives the most probable values for lignin corrected for ash (both on the extractive free and unextracted wood bases) and the corresponding methoxyl content of these lignins.

TABLE 10.—"KLASON" LIGNIN ON TROPICAL WOODS AND CORRESPONDING METHOXYL CONTENT OF THESE LIGNINS

(Unextracted, ovendry basis)

Wood	Corrected (extractive-free basis), percent	Corrected (unextracted basis), percent	Methoxyl in lignin, percent
I	31.80	29.08	19.75
II	27.65	24.03	19.35
III	32.62	29.33	18.85
IV	26.83	24.36	20.8
V	28.20	26.11	21.7
VI	31.80	29.72	18.3
VII	23.51	20.27	18.9
VIII	32.92	29.50	17.65

It will be noted that four of these woods (III, VI, VII, and VIII) yield lignin residues with methoxyl contents considerably below those given by our native American hardwoods (20–21.5 percent). Whether or not this is due to impurities in the lignin is as yet undetermined. However, two experiments throw some light on this question. The lignins from VI (*Cordia alliodora*) and from VIII (*Licaria cayennensis*) were heated with 1 percent potassium carbonate solution, followed by cold digestion for about 22 hours. A considerable portion of the lignin dissolved in the case of VI and smaller amounts in the case of VIII. The lignin residues were filtered and washed successively with water, acetic acid, and water and dried. Methoxyl determinations were then made on the residues. That from VI contained 18.45 percent methoxyl and that from VIII contained 17.4 percent methoxyl, indicating that no appreciable change in methoxyl content had occurred and that no acidic substance (lower in methoxyl than the Klason lignin) had been removed preferentially. It seems probable (but by no means *proved*) that these lignins contain fewer syringyl groups than do the lignins of our native hardwoods. This also appears to be true for the lignin of quebracho wood (*Schinopsis* sp.) (*26*). On the other hand, it will be noted that both samples of *Manilkara bidentata* (IV and V) give lignin methoxyl values falling within the usual range, and that samples I and II closely approach the lower values within this range.

The lignin content of these woods merits brief discussion. Those of woods I, III, VI, and VIII are much higher than those usually found in our native American hardwoods; VII is within the usual hardwood range, whereas the others show a relatively high lignin content, but one similar to that found in some of our American oaks. For com-

parative purposes, a few Klason lignin analyses on angiosperms of the Northern Hemisphere may be cited. All the data in Table 11 are given on the basis of the ovendry unextracted wood.

It is interesting to note that, although in four instances, the percentage methoxyl in the lignin of tropical woods was *below* that usually found in the lignin fraction isolated from native hardwoods, the methoxyl content of the *woods* themselves was at times *higher* than that found in our native angiosperms. The percentage methoxyl in the tropical woods (on the unextracted basis) ranged from 5.4 to 7.4 percent. The methoxyl range for native American hardwoods is ordinarily 3.4 to 6.5 percent. Only in the case of a sugar maple was a methoxyl content as high as 7.25 percent found (*9*).

Methoxyl Content of Hemicelluloses

Most of the methoxyl groups in wood are associated with the lignin. Very small amounts may be associated with extractives. However, an appreciable amount of methoxyl resides in the hemicellulosic fraction. The percentage of such methoxyl has been calculated as follows: In each case the percentage of lignin [on the extractive-free wood basis (cf. Table 10)] is multiplied by the methoxyl content of the lignin. This gives the "lignin methoxyl" in the extractive-free wood. This is then subtracted from the corresponding total methoxyl in the extractive-free wood (cf. Table 10). This difference multiplied by (100 minus the percent extractives in the wood) and divided by 100 is the percentage methoxyl *not in the lignin or in the extractives*. For purposes of analytical summation, this value is recalculated to "percentage CH_2." The reason for this is that the nonlignin methoxyl appears to be associated largely with the uronic acid groups in the wood (*19*). In determining the uronic acid groups in wood, only one oxygen and one hydrogen atom in each OCH_3 group were included in the final calculation. Thus the "CH_2 portion" of the OCH_3 was *not* accounted for in the uronic acid determination.

Values for hemicellulosic methoxyl and for the respective "CH_2 percentage" are given in Table 12

Cell Wall Polysaccharides

Introduction

The proximate determinations of alpha-cellulose and hemicelluloses in a wood are best carried out by initially preparing holocellulose and then isolating the two fractions from this starting product. Under ideal conditions, holocellulose retains all the carbohydrates of the cell wall. Two general methods have been proposed for the preparation of holocellulose but, in the experience of the Institute, the so-called "chlorite" procedure is the more convenient (*13, 27*). This depends on suspending a convenient, weighed, air-dried, unextracted sample in water and heating at 70–80° C. with successive portions of acetic acid and sodium chlorite. The action of these reagents gives rise to chlorine dioxide, which converts most of the lignin into water-soluble chlorinated and/or oxidized products (*3*) and which also removed extractives. It is important, however, to retain small amounts of lignin in the holocellulose. Complete lignin removal permits the removal of significant amounts of hemicelluloses as well. Inasmuch as the method is empirical, and as different wood species require varying numbers of such chlorite treatments, protracted orienting experiments were required to determine the optimum conditions of delignification. These initial experiments (which showed the danger of over chloriting) need not be described. They are mentioned simply to show that each wood required special study. The optimum number of successive chloritings for woods I, III, IV, V, VI, and VII was four. II required six and VIII required five chloritings. The technique used has been described in detail by Wise, Murphy, and D'Addieco (*27*). The isolated holocellulose (prepared from 5-gram samples of wood) were cooled in an ice-brine bath, filtered by suction, washed with ice water and acetone, and air dried.

Quantitative Isolation of the α-Cellulose and Hemicellulose Fractions

The air-dried holocelluloses were weighed and extracted two hours at 20° C., under nitrogen, with 100 ml. 5 percent aqueous potassium hydroxide, with occasional shaking. The suspension was filtered promptly by suction into an *excess of acetic acid*, and the residue was then washed successively with 50 ml. 5 percent potassium hydroxide, with water and, finally, with dilute acetic acid and water. The filtrate and washings (which were strongly acid) were then treated with 4 to 5 volumes of 95 percent ethanol to precipitate the hemicellulose (fraction A). The fibrous residue, after acetone washing, was

TABLE 11.—KLASON LIGNIN CONTENT OF HARDWOODS OF THE UNITED STATES

(Unextracted, ovendry basis)

	Big-tooth Aspen	Quaking Aspen	Beech	Yellow birch	Paper birch	Sugar maple	Red maple	Basswood	Chestnut oak	Overcup oak	Southern red oak
Lignin, %	16.3[b]	19.3[a]	21.0[a]	22.7[a]	19.4[a]	20.3[b]	22.8[a]	20.0[a]	24.3[a]	24.4[c]	22.5[c]
	16.9[b]	19.2[a]	20.6[b]	18.6[b]	20.5[a]	21.8[b]					
			22.3[b]	20.2[b]	17.6[b]						
					19.6[b]						

[a]Data (in part unpublished) from the U. S. Forest Products Laboratory.
[b]Data of Freeman and Peterson.
[c]Analyses made at The Institute of Paper Chemistry.
Methoxyl content of overcup oak, 19.5 percent; of southern red oak 20.3 percent. Unfortunately, the methoxyl content of the lignins under [a] and [b] were not determined.

TABLE 12.—METHOXYL NOT IN LIGNIN OR EXTRACTIVES; "CH_3 VALUES

Wood	Total methoxyl in *extractive-free* wood (A), percent	Lignin methoxyl (basedon extractive-free wood) (B), percent	Methoxyl[1] not in lignin or extractives (based on unextracted wood), percent (=C)	"CH_3 values" corresponding to C, percent
I	7.0	6.28	0.66	0.30
II	6.45	5.35	0.96	0.43
III	7.25	6.15	0.99	0.45
IV	6.85	5.58	1.15	0.52
V	7.7	6.12	1.46	0.66
VI	7.05	5.82	1.15	0.52
VII	5.40	4.44	0.83	0.37
VIII	6.45	5.81	0.57	0.26

[1]Computed by subtracting B from A in each case and multiplying by an appropirate factor for converting from the extractive-free to the unextracted wood bases.

air dried and extracted with 100 ml. 16 percent potassium hydroxide (under conditions identical with those given above). The suspension was filtered into an excess of acetic acid and washed successively with 50 ml. 16 percent potassium hydroxide, water, 10 percent acetic acid, and water. The filtrate was precipitated by means of an excess of alcohol, thus giving hemicellulose B. The two hemicellulose fractions (A + B) were combined and treated as indicated below. [The only exception to the isolation treatment outlined was that of II (*Pseudosamanea guachapele*). Owing to extreme difficulties in filtration, especially after alkaline extraction, the holocellulose was treated *only* with 5 percent aqueous potassium hydroxide.]

The insoluble fibrous residue from these extractions has been termed arbitrarily "alpha-cellulose," largely for the sake of convenience. The significance of this determination will be discussed later in the report.

These alpha-celluloses were then corrected for ash, residual lignin, residual uronic anhydride, and residual (corrected) xylan. With the exception of II, ash and lignin corrections were usually slight, whereas the corrections for uronic acid and xylan were often significant. This is shown in Table 13.

TABLE 13.—ALPHA-CELLULOSE CONTENT OF THE TROPICAL WOODS[a]

(Unextracted, ovendry basis)

Wood	Alpha-cellulose (uncorrected), percent	Alpha-cellulose (corrected for ash and lignin), percent	Alpha-cellulose (corrected for ash, lignin, residual uronic anhydride and xylan), percent
I	46.55	46.45	44.15
II	46.05	45.35	41.80
III	48.05	47.80	45.65
IV	47.70	47.50	44.40
V	46.40	46.30	43.85
VI	45.70	45.35	42.70
VII	42.85	42.80	40.40
VIII[b]	46.25	46.25[b]	43.65

[a]Average of duplicate determinations; results given to the nearest 0.05 percent.

[b]Owing to the unusually low ash content of the original wood, *Licaria* alpha-cellulose was not corrected for ash; the lignin content of the cellulose was only 0.04 percent; hence, this correction is negligible.

The precision of the alpha-cellulose determination leaves much to be desired. Duplicate determinations showed variations of 0.15 to 0.7 percent.

The over-all results indicate that most of these tropical woods are relatively high in alpha-cellulose. This is surprising in view of the high lignin values and the appreciable extractive content. Whereas the values (i.e., alpha-cellulose corrected for lignin and ash) fall below those of our native aspen (50–51 percent), yellow birch (51 percent), beech (51.2 percent), and elm (55.2 percent), they are considerably higher than those of our native overcup oak (41.1 percent), red oak (37 percent) (*28*), and post oak (41.9 percent) (*12*).

Hemicellulose Content of the Woods

The flocculent, combined hemicellulose fractions (referred to in the preceding section) were centrifuged and washed thoroughly with warm 95 percent alcohol, absolute alcohol, and anhydrous ether. The white powdery products were then dried to constant weight at 100° C. The procedures were carried out quantitatively. Ash determinations were made on the various hemicelluloses by careful charring and ignition in the presence of a few drops of concentrated sulfuric acid. The "sulfated ash" was then weighed and extracted repeatedly with hot water. The *water-insoluble residue* was also determined. This permitted the estimation of total ash, insoluble ash, and water-soluble ash. As a result of previous experience, the assumption was made that the entire *water-soluble* ash was present as potassium sulfate, and that the potassium in this ash had been present originally in the form of $-\overset{\overset{O}{\parallel}}{C}-OK$ in the uronide portion of the hemicellulose fractions. Whereas the validity of such an empirical assumption might be questioned, experiments with other wood hemicellulosic fractions indicate that, in the main, this hypothesis appears to be justifiable. Potassium acetate, formed in large quantity during the hemicellulose isolation, is completely removed by repeated washing with warm alcohol. Hence the soluble sulfated ash was calculated to *potassium* for which due correction was made. A correction was also made for the insoluble ash in the hemicellulose.

The following is a specific example of such ash corrections. In one analysis the wood of *Manilkara bidentata* (from Surinam) yielded 18.32 percent ash-containing hemicellulose. The soluble ash (calculated as K_2SO_4) was 21.56 percent, which corre-

sponded to 9.66 percent potassium. The insoluble ash was 0.74 percent. Then (recalculated on the original wood basis):

$18.32 \times 0.0966 = 1.78$ and
$18.32 \times 0.0074 = 0.14$
$18.32 - (1.78 \text{ and } 0.14) = 16.4$ percent (corrected hemicellulose value).

Table 14 shows the results of duplicate determinations giving the corrected hemicellulose values.

TABLE 14.—HEMICELLULOSES IN TROPICAL WOODS
(Unextracted, ovendry basis)

Wood	Hemicelluloses (corrected for soluble and insoluble ash) percent
I	14.45, 14.14
II	12.90, 13.93
III[a]	12.39, 11.81
IV	14.82, 15.24
V	16.11, 16.40
VI	17.12, 16.68
VII[a]	19.95, 20.13
VIII	10.84, 11.07

[a] The hemicelluloses from III and VII still gave slight blue colorations with iodine, indicating that small amounts of starch may be present as a contaminant.

The above table also gives an index of the precision, as well as of the limitations, of the method. In the case of II (*Pseudosamanea guachapele*), the lack of precision may be ascribed to extreme difficulty in filtering the swollen holocellulose.

It has been noted that all alpha-cellulose fractions retain appreciable amounts of xylan and uronic anhydride residues. Provided the *sum* of these residues is subtracted from the *sum* of the total xylan and uronic anhydride present in a hardwood, the difference should give an approximate measure of the hemicellulose content of that wood. (The assumption here is that the other sugar units, such as mannose, galactose and arabinose, are present in negligible amounts.) Such a calculation was made and the results are those given in Table 15; these may then be compared directly with those given in Table 14. With the exception of VII (the hemicelluloses of which apparently retain some starch), all the results in Table 15 are appreciably higher than those in Table 14. This discrepancy was not unexpected. Past experience has shown that, in isolating hemicelluloses from the holocellulose of hardwoods, small losses of cell-wall carbohydrates occur quite regularly. Experience has also shown that, in the presence of hexosans (like those ocurring in wood), the xylan determination gives slightly high values, possibly because of the formation of hydroxymethylfurfural (*29*). Hence, in most cases, the true value of a hemicellulosic fraction is probably intermediate between the values given in Table 14 and those shown in Table 15.

TABLE 15.—SUM OF XYLAN AND URONIC ANHYDRIDE IN WOODS
(Other than those in α-cellulose)
(Unextracted, ovendry basis)

Wood	Xylan + uronic anhydride (corrected for these components in alpha-cellulose), percent
I	15.7
II	15.6
III	13.0
IV	16.75
V	16.55
VI	17.25
VII	18.7
VIII	12.15

With the exception of sample VII, the hemicellulose values fall well below those usually found in our native hardwoods [e.g., an unextracted specimen of aspen wood, analyzed by a similar procedure, contained about 21 percent hemicelluloses (*27*), a sample of red oak contained 20.1 percent and a sample of overcup oak yielded 20.5 percent hemicellulose (*28*).]

The assumption is generally made that the acetyl groups of a wood are closely and almost quantitatively associated with the hemicelluloses. If this be true and it is strongly supported by various analytical data (cf. RITTER's work on holocellulose), then the total hemicelluloses *plus* acetyl groups may be approximated by subtracting the alpha-cellulose content of wood from its holocellulose content. In the absence of direct hemicellulose determinations, such calculations have been made from data supplied by the U. S. Forest Products Laboratory (*21*). The results given in Table 16 show the marked differences between our native hardwoods and those of the tropics. Only VII falls within the usual range of domestic angiosperms, and only elm (which has an unusually high alpha-cellulose content) approaches the range of the tropical woods. In the main, the differences are striking.

Summative Proximate Analyses

Introduction

Ideally, the summative analysis of any wood should include the important components and functional groups without overlapping and without omission. In other words, a summative analysis should account for 100 percent of the original wood. Whereas there are a number of wood analyses in the literature which *appear* to give such a precise summation, in the experience of the Institute, this is largely due to the happenstance of small, compensating errors. These have been discussed quite fully by WISE, MURPHY, and D'ADDIECO (*27*). Realizing the limitations in precision of some of our analytical techniques (e.g., for determining lignin, hemicelluloses, and alpha-cellulose), summations of 97–102 percent must be considered entirely satisfactory.

TABLE 16.—COMPARISON OF SUMMATION OF HEMICELLULOSE AND ACETYL CONTENT OF TROPICAL WOODS WITH THAT OF NATIVE NORTH AMERICAN HARDWOODS[1]

Wood	Hemicellulose plus acetyl, percent
I	15.4
II	14.9
III	13.3
IV	16.35
V	17.35
VI	18.2
VII	22.25
VIII	11.7
Quaking Aspen	29.7, 28.9
Yellow birch	21.5
Paper birch	32.4, 31.1
Beech	24.5
Chestnut oak	28.9
American elm	17.7
Red maple	26.5
Basswood	28.5

[1] Calculated from data (in part unpublished) furnished by the U. S. Forest Products Laboratory.

It might be well to outline the concepts on which summative analyses are based, and some of the assumptions made by the analyst. This can best be done by use of a schematic figure (Fig. 1), which is very similar to that given by Wise and Ratliff (*28*), showing the main components of the cell walls of wood. This is a modification of a scheme originally devised by Norman (*18*). For purposes of simplicity, the extractives have been omitted. It will be noted that this figure shows *two* possible ways of defining alpha-cellulose, depending on a hemicellulosic "border zone." If we isolated alpha-cellulose by an analytical scheme, this border zone would be included. This means that all alpha-cellulose fractions isolated from any wood contain some units other than glucose—e.g., xylose, uronic anhydride, mannose, etc. If, however, we define alpha-cellulose academically as containing *only* alkali-resistant long chains made up solely of β-D-glucopyranose units, then this border zone must be omitted. The boundary line between the hemicelluloses and true cellulose depends upon the viewpoint of the wood chemist, and should be stated unequivocally. The term alpha-cellulose may have a dual significance and on the definition of our choice will depend what wood components should be included in any scheme of summative analysis.

The difference in the alpha-cellulose concept may be illustrated by making reference to black spruce (cf. Wise and Ratliff). In this wood, the total hemicelluloses recovered by successive treatments with potassium hydroxide were 17.5 percent (based on extractive-free wood). The residual "alpha-cellulose" (ash- and lignin-free) was 51.5 percent. However, this alpha-cellulose fraction retained 7.06 percent mannan, 1.7 percent xylan, and 2.1 percent uronic anhydride. Calculated on the basis of the original (extractive-free) wood, these values become 3.6 percent mannan, 0.88 percent xylan and 1.08 percent uronic anhydride. In other words, the total non-glucose units retained by the isolated alpha-cellulose was about 5.6 percent. If correction is made for these extraneous units, then the "academically" defined "pure" alpha-cellulose emerges, and the content of *this* "pure" cellulose is 45.9 percent (instead of 51.5 percent). If then we arbitrarily *add* to the original hemicelluloses the "border line" hemicelluloses, this fraction rises from 17.5 percent to about 23.1 percent. It is obvious that in any summative analyses, *two* distinct types of summations may be used.

In recognition of these two viewpoints, *both* concepts of alpha-cellulose have been used in the present analytical summations.

In one series the academic concept has been followed (where cellulose is corrected, not only for ash and lignin, but also for xylan and uronic anhydride as well). In the other series of analyses, the analytical definition of alpha-cellulose has been retained.

The one set of summative wood analyses (Table 17) includes ash, total extractives, total lignin (corrected for ash), total hemicelluloses (isolated from the holocellulose and corrected for ash), alpha-cellulose (corrected for lignin and ash), and acetyl. The other set of summative analyses (Table 18) includes ash, extractives, lignin (corrected for ash), alpha-cellulose (corrected for residual ash, lignin, xylans, and uronic anhydride) and "CH_2" (arising from methoxyl not in the lignin or in the extractives), total xylan, and total uronic anhydride. It will be noted that mannose units have not been determined because of their subordinate amount and because of the analytical difficulties. Furthermore, tannins, coloring matter and starch (which occur in the extractives) naturally are not included in any

TABLE 17.—SUMMATIVE ANALYSES OF TROPICAL WOODS

(Unextracted, ovendry basis)

All values in percent

	I	II	III	IV	V	VI	VII	VIII
Total extractives (loss in weight)	8.55	13.15	10.1	9.2	7.5	6.55	13.75	10.4
Ash	0.33	0.58	0.19	0.7	0.37	0.98	0.85	0.025
Acetyl	1.1	1.5	0.81	1.3	1.1	1.3	2.2	0.76
Lignin (corrected for ash)	29.1	24.05	29.35	24.35	26.10	29.7	20.25	29.50
Alpha-cellulose (corrected for lignin and ash)	46.45	45.35	47.8	47.5	46.30	45.35	42.8	46.25
Hemicelluloses (corrected for ash)	14.3	13.4	12.50	15.05	16.25	16.9	20.05	10.95
Total	99.83	98.03	100.75	98.10	97.62	100.78	99.90	97.885

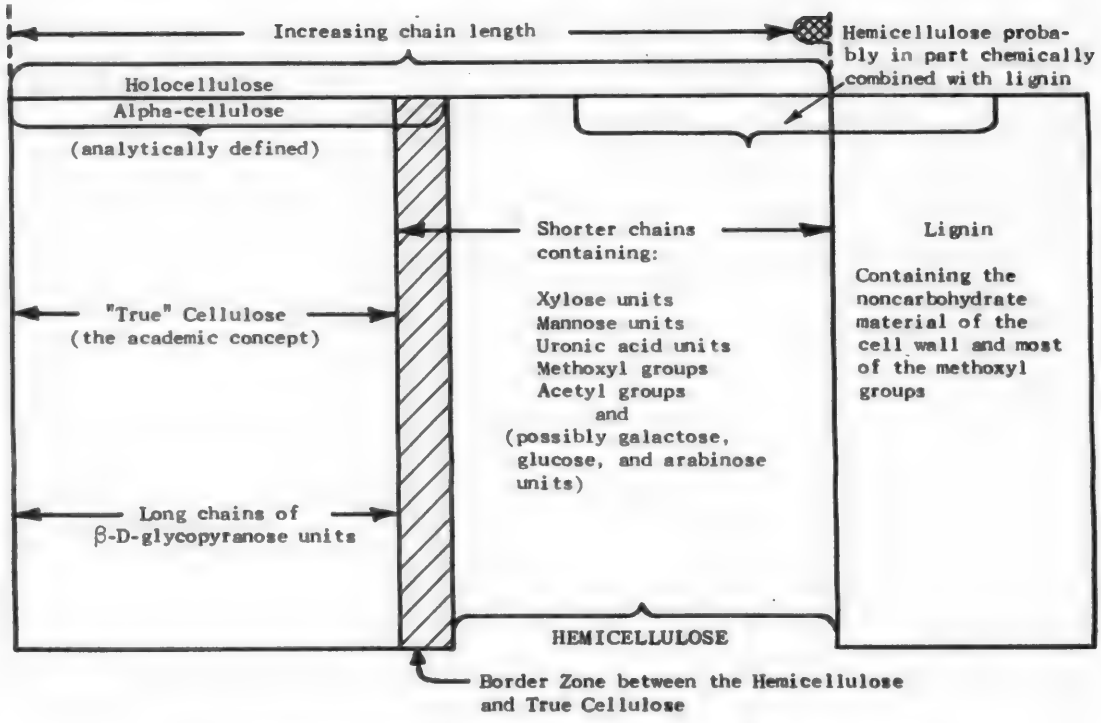

Fig. 1.—Schematic Diagram. Components of the extractive-free cell walls of wood.

summation, although traces of the latter may be present in the hemicellulose fractions. The distribution of nitrogen over the various wood components is also entirely unknown and, therefore, this component is not included in either summation. (It is probable but not proved that some nitrogen may be precipitated with Klason lignin and also retained by holocellulose.) The methoxyls in lignin and the small amount present in the extractives are also not included, otherwise overlapping would occur. Up to the present, no quantitative method exists for determining the small amounts of pectic materials occurring in wood. Most of these are retained by the hemicelluloses and smaller amounts probably are found among the extractives. Inasmuch as they are, in the main, polygalacturonides, they would (in one of the summations) be included under the percentage of uronic anhydride. It is of some interest to compare these data with those obtained from quebracho wood (*Schinopsis sp.*) using similar summations (given in Table 19).

Resistance of Tropical Woods to Boring by the Cadelle Larva

(*Tenebroides mauritanicus* Linn)[1]

The cadelle is a cereal-infesting beetle that is frequently found in mills, granaries, and storehouses. When the larvae complete their growth and are ready to transform to the pupal stage, they frequently seek seclusion by boring into the wooden bin or receptacle that holds the infested material.

[1] Reported by J. B. Anderson.

TABLE 18.—SUMMATIVE ANALYSES OF TROPICAL WOODS

(Unextracted, ovendry basis)

All values in percent

	I	II	III	IV	V	VI	VII	VIII
Total extractives (loss in weight)	8.6	13.15	10.1	9.2	7.5	6.55	13.75	10.4
Ash	0.33	0.58	0.19	0.7	0.37	0.98	0.85	0.025
Acetyl	1.1	1.5	0.81	1.3	1.1	1.3	2.2	0.76
Lignin (corrected for ash)	29.1	24.05	29.35	24.35	26.10	29.7	20.25	29.50
Alpha-cellulose (corrected for lignin, ash, xylan, and uronic anhydride)	44.15	41.8	45.65	44.4	43.85	42.7	40.4	45.65
Total xylan	13.2	14.3	11.7	15.6	14.75	14.2	16.1	11.25
Total uronic anhydride	4.8	4.8	3.8	4.25	4.25	5.85	5.0	3.45
"CH_3" (calculated from MeO not in lignin or extractives)	0.3	0.43	0.45	0.52	0.66	0.52	0.87	0.26
Total	101.58	100.61	102.05	100.32	98.58	101.8	98.92	99.295

TABLE 19.—SUMMATIVE ANALYSIS OF QUEBRACHO WOOD

(Unextracted, ovendry basis)

All values in percent

	I*	II*
Total extractives by loss in weight	36.40	36.40
Ash	0.48	0.48
Acetyl	1.02	1.02
Lignin[a]	15.20	15.20
Alpha-cellulose	28.80	
Alpha-cellulose (corrected for xylan and mannan)		26.70
Hemicelluloses (corrected for ash)	16.45	
Xylan		14.3
Uronic anhydride		4.05
Mannan		0.65
"CH_2" (calculated from MeO not in lignin or extractives)		0.5
Total	98.35[b]	99.30[c]

[a] Lignin contained 18.0 percent methoxyl.
[b] cf. (26).
[c] Unpublished data, The Institute of Paper Chemistry.
* I corresponds to Table 17 and II to Table 18.

The larvae are capable of boring through a variety of materials, including lead and aluminum foil.

Small blocks (about 1 by 1 by 2 inches) of the eight tropical woods were placed in half-pint mason jars with twelve cadelle larvae per jar. They were kept in a room favorable for insect activity at a controlled temperature of 83° F. and a relative humidity of 65 percent.

The larvae bored into two of the woods, *Pseudosamanea guachapele* and *Cordia alliodora,* within one day. Boring continued during the observation period of one week. The other woods showed no signs of attack.

Table 20 lists the woods and indicates whether or not they were attacked by cadelle larvae within one week.

TABLE 20

Wood	Damage by cadelle larvae
Cordia alliodora	Boring begun within one day
Hymenaea courbaril	Not attacked
Licaria cayennensis	Not attacked
Manilkara bidentata (Puerto Rico)	Not attacked
Manilkara bidentata (Surinam)	Not attacked
Ocotea rubra	Not attacked
Pseudosamanea guachapele	Boring begun within one day
Tabebuia guayacan	Not attacked

These interesting results merit further study.

Discussion

Analytical data, although entirely valid for the samples used in making the physical tests on tropical wood conducted at New Haven, are limited to composite samples *from only a small number of logs.* This fact cannot be over-emphasized because, in a study such as this, no generalizations are possible, and any prognoses or working hypotheses must be made with the greatest reservation.

The summative analyses of the eight samples of tropical woods indicate that their chemical composition is quite different from that of our native hardwoods. Whereas the alpha-cellulose content falls within a range often found in North American angiosperms, the lignin content is often significantly higher and the hemicellulose content is frequently lower than that of the hardwoods of the United States. In fact, in lignin and hemicellulose content, the tropical woods show a (superficial) resemblance to our native conifers, especially in lignin, acetyl, and hemicellulose contest.

Even a cursory exploration of the extractives content of a few of these woods, however, permits the analyst to make certain predictions regarding their probable resistance to fungal and insect attack. Because of the tannin content and absence of starch, *Manilkara bidentata* woods (both from Puerto Rico and from Surinam) should be durable, resisting both decay and insect attack. Our analytical data are insufficient to indicate whether or not these woods would be resistant to the degradations of the marine borer.

Licaria wood should also fall sharply into the class of insect- and fungus-resistant woods. This *a priori* judgment is strengthened by the high lignin content and the low hemicellulose content. Provided the present hypothesis regarding the protective action of silica in wood against the marine borer is justified, then *Licaria,* which is extremely low in ash, would certainly not be protected by virtue of any silicates. *Tabebuia guayacan* contains no tannins and gave only a slight test for starch. It contains lapachol which, because of its phenolic nature and quinone structure, should serve to render the wood resistant both to insect and fungal attack. Judging from the relatively low ash content of the wood, no marked resistance to the marine borer would be expected, unless extractives furnish such protection.

Our analytical data throw little light on the probable durability of *Pseudosamanea guachapele.* This bulky, fibrous wood contains starch, and no tannins; its nitrogen content is relatively high. These would militate strongly against its durability. On the other hand, it contains about 13 percent unexplored extractives, a part of which may be phenolic. Hence, our data contribute nothing either *pro* or *con.* The ash content was not very high and, from the silica analysis made at Yale, there is little *a priori* evidence that this wood would be teredo resistant, unless the extractives function as inhibitors.

On the basis of our analyses alone, no judgments can be made regarding the durability of *Ocotea rubra,* which contains small amounts of steam-volatile material (but which contains no tannins and some starch). Preliminary reports from Yale indicate that this wood is resistant to the marine borer. This resistance is evidently not due to siliceous matter because this wood has a low ash content. It is quite possible however, that some extractive may be in part responsible for this resistance.

The ether extractives of *Ocotea* are very interesting and deserve a much closer study. The wax-like substance found among the ether extractives may account, in part at least, for the very slow rate of moisture absorption by the heartwood.

Cordia allidora contains small amounts of a fragrant essential oil, no tannin, and some starch, and a relatively high nitrogen content. Judging from these components, the wood may or may not be durable. Analytic results, *per se,* throw little light on this subject. Despite its relatively high ash content, there is no evidence at hand that it would be resistant to the teredo.

Courbaril, containing both tannin *and* starch, might vary in its resistance to insect or fungal attack (depending on the variation in the content of these extractives). Its ash content is relatively high, but silica data obtained at Yale would indicate that this component is very low, and there is no *a priori* evidence that it would be teredo resistant.

In view of the actual laboratory findings given in a previous section by the entomologist of The Institute of Paper Chemistry, these *a priori* judgments regarding the various tropical woods are of interest.

With the present paucity of data, it is impossible to correlate the interest shrinkage data obtained at Yale with any specific chemical component of these woods. However, the following tabulated data may be of some interest.

It will be noted that the two tropical woods, which have approximately the same specific gravity as the three native woods, show both lower volumetric shrinkages and lower holocellulose contents. Only extensive data on a large number of tropical and native woods handled statistically can show whether this relationship is valid or due to happenstance.

The high lignin content and relatively low hemicellulose contents of at least four of these tropical woods (i.e., I, III, VI, and VIII) would militate against their use in chemical pulping. Even the production of dissolving pulps (which rely on a relatively high alpha-cellulose content, and which are used for conversion into rayon, cellophane, and cellulose esters and ethers) would not be indicated. Of the remaining woods, only VII (despite its high extractive content) might prove interesting because of its low lignin and "normal" hemicellulose content. However, no positive statements regarding the usefulness of any tropical woods for pulping purposes can be made without actual pulping experiments.

The use of these woods in wood distillation, if acetic acid is to be recovered, is *not* indicated. On the other hand, their methoxyl contents are sufficiently high to warrant recovery of methanol and, in such dense woods as *Licaria cayennensis* and *Manilkara bidentata,* charcoal resulting from wood distillation might prove interesting.

The exploration of extractives from certain of the tropical woods as insecticides or fungicides might also be warranted.

TABLE 21

Wood	Specific gravity (green volume basis)	Volumetric shrinkage, percent	Holocellulose (ovendry, unextracted wood basis), percent	Comments
Pseudosamanea guachapele	0.56	7.6	60.3	Holocellulose taken as sum of the percentages hemicellulose, acetyl and alpha-cellulose
Ocotea rubra	0.56	11.6	61.1	Ditto
Yellow birch (*Betula lutea*)	0.55	16.7	72.5 76.45*	Holocellulose by direct determination (U. S. Forest Products Lab.)
Chestnut oak (*Quercus montana*)	0.57	16.7	75.7	Ditto
Beech (*Fagus grandifolia*)	0.56	16.3	75.7 76.85*	Ditto

*Data of Freeman and Peterson on heartwood.

Recommendations for Future Work

After conference with Dr. Wangaard of the Yale School of Forestry, it is proposed:

(1) To make a complete analytical study of the heartwood of the following woods:

Dicorynia paraensis ("Angelique")
Couratari sp. ("Tanary")
Eschweilera sagotiana
Tectona grandis (teak)
Swietenia macrophylla (mahogany)

and of a limited number of other woods which have been found resistant to *Teredo navalis,* with the objective of uncovering possible wood components to which this resistance is due.

(2) To make a more detailed study of the ash of these woods (possible spectrographic analyses).

(3) To extend the investigations of the extractives of *Ocotea rubra,* which apparently have a bearing on the water sorption of the wood and, possibly, on its *Teredo* resistance.

(4) To expose blocks of these woods to the wood-boring larvae of certain destructive insects (e.g., cadelle—*Tenebroides mauritanicus)* to obtain data on their durability with regard to insect attack.

(5) To study the possible insecticidal effects of extractives from these woods on such insects.

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Discussion

Carl de Zeeuw (New York State College of Forestry): Do you know whether Dr. Wise is planning to expand the study to include new species and also analysis for other components?

Irving H. Isenberg (Institute of Paper Chemistry): The paper is a report of the work as of June 1950. Additional species have been analyzed since then and will be published. Determa *(Ocotea rubra)* has shown a considerable amount of waxy extraneous component and other species may give interesting extractives also.

F. F. Wangaard (Yale School of Forestry): I am impressed with the relationship between chemical composition as reported and certain physical and mechanical properties. For example, the paper describes the finding of a considerable quantity of an extraneous waxy component in Determa *(Ocotea rubra)*. Our studies have shown this species to be exceptionally slow in seasoning.

Dr. Isenberg: Other relationships may also be found. It appears that the holocellulose content may be related to volumetric shrinkage.

Mr. X: Given woods of a definite specific gravity, is there a possible correlation between volumetric shrinkage and lignin or holocellulose content?

L. E. Wise (Institute of Paper Chemistry): The number of cases is so small that any possible correlation must be pointed to with due reservation. The tropical woods *Pseudosamanea guachapele* and *Ocotea rubra,* having a specific gravity of 0:56 (green volume basis) and 60.3 and 61.1 percent holocellulose, respectively, showed a far lower volumetric shrinkage than did yellow birch, chestnut oak and beech (specific gravities 0.55–0.57) the holocellulose contents of which ranged from 72.5 to 76.85 percent. Teak also showed both a very low volumetric shrinkage and a very low holocellulose content.

Mr. X: Do these woods show marked resistance to wood boring insects such as the cadelle larvae)?

Mr. Wise: Most of the woods remain unattacked by *Tenebroides mauriticanus* linn for relatively long periods except in the case of *Cordia alliodora* and *Pseudosamanea guachapele.*

Mr. X: Are the ash components of these woods of marked practical interest; e.g. *Licaria cayennensis.*

Mr. Wise: Since the paper was written, ash components were studied spectographically and certain interesting relationships between the eight tropical wood ashes and those of our native hardwoods were noted; whereas all of the ashes of hardwoods of the U. S. A. examined at the Institute showed strong potassium lines, those of the tropical woods often showed weak or at most, medium, for potassium. *Licaria cayennensis* contained surprisingly little total ash (*ca.* 0.025 percent). Whether this is the case with only the one specimen examined by us, or is characteristic of other specimens is still undetermined. A number of woods not included in the present study which are high in SiO_2 are resistant to marine borers. However, *Ocotea rubra* which is also borer-resistant, is low in SiO_2; thus illustrating the danger of generalization.

TECHNICAL SESSION X—Fri., May 11, 1951, 9:00 A. M.

General Subject: Glues and Gluing—Getting Better Results with Present Materials

Co-Sponsor: Society of the Plastic Industry

Chairman: James F. Hamilton—**Recorder:** Don Redfern

Glue Line Doctor[1]

ALAN A. MARRA, *Research Engineer, Engineering Research Institute, University of Michigan*

Glue is depicted as living matter having certain life processes to accomplish as it develops to a bond. The growth is influenced by analegous environmental and climatic conditions which affect its strength and integrity during its adult life as a bond. Certain visible characteristics are thus imparted to a glue line and these are usable for diagnosis of difficulties. Treatments are recommended to alleviate the observed symptoms.

Introduction

STATEMENTS frequently found in use-instructions for adhesives illustrate a need for some means of appraising the performance of an adhesive during the production of glued constructions: "Shorter assembly times should be observed with dry stock." "Increase the spread when veneer is rough." "For increased durability decrease the amount of flour extension." "Increase the pressure for denser species." "Joint surfaces should be properly machined and free from contaminations."

Each statement also illustrates lack of certain definite information and gives rise to obvious questions: How dry is dry stock? How long is a shorter assembly time? What is durability and how do extenders and fortifiers affect it in the various constructions and end uses? How, in fact, is durability affected by variations in gluing technique with the same formulation? How does pressure operate on a glue line and what is the actual work done by it? When is a joint surface in suitable condition for gluing both as to its topography and its chemical characteristics? These and many other questions are blocking the road to continuous successful use of wood adhesives and also to the development of improved formulas.

Faced with such questions it is little wonder that the adhesive user is led to make the rounds of the market in search of the ideal formulation, often at great expense. Adding to his difficulty is the dearth of information and test methods which might aid him in appraising both the adhesive, and the manner and construction in which it is to be used.

Assuming that we must live with this situation for some time, this paper will attempt to develop a concept of the bonding process which, though it may not answer specific questions, might help to create a better understanding of the factors influencing the gluing operation, and thus lead to such improvements as may be indicated. The premise is made that a substantial majority of the wood adhesives in use today are capable of adequate performance, within broad limits, *provided they are properly handled.*

It is difficult if not impossible to establish universal hard and fast rules of operation for a process such as wood gluing in which the factors affecting performance of the glue are not only numerous but also interacting. Moreover, since the combinations of factors vary so greatly from plant to plant and since there is such variation in the quality of the products manufactured and in the available equipment and personnel, the feasibility of specific recommendations would likewise vary. Consequently there is little hope for an individual to find written down somewhere exactly how he should operate. By learning how glue functions however, he at once becomes free to devise his own procedures to best suit his particular circumstances.

The approach to be taken is to bring glue to life and endow it with certain life processes which are calculated to result in its maturation to a bond. Disorders thus develop as a consequence of unfavorable conditions and these yield symptoms which are useful in diagnosis. Treatments may then be prescribed, in accordance with good technical practice, to give rapid relief. Finally some preventive medicine is offered to help reduce defective glue lines.

In previous work,[2] [3] an attempt was made to extend the observable features of a glue line into a characterization system which would permit the deduction of a large number of factors whose effects are capable of registering definite patterns in the adhesive layer. This system, while by no means infallible nor yet fully developed to cover all adhesive activity, can be a valuable production control tool. It possesses the distinct advantage over other methods of control in the speed and ease with which observations are made, and also *in showing in which direction corrective action should be taken.*

[1] This paper is based in part on information obtained in connection with a study of the use of adhesives in furniture manufacture sponsored by the National Association of Furniture Manufacturers through the Engineering Research Institute of the University of Michigan and the Department of Wood Technology in the School of Natural Resources.

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The Living Nature of Adhesives

In order to understand the functioning of an adhesive, and therefore the methods for controlling its activity, it has been found helpful to visualize it as living matter, matter which must perform certain life processes in developing to a bond. A number of evolutionary forces acting during the formative stages of its life, may therefore be expected to shape its character and determine the integrity with which it will maintain its position during its adult life as a bond.

As previously depicted[2,3] the life processes of an adhesive bond are:

1. Flow to a continuous film.
2. Transfer to the opposite unspread surface.
3. Penetrate the pores of the wood.
4. Wet the wood substance.
5. Solidify to a strong mass.

The conditions under which these processes take place, likened to those of a growing person, are:

Heredity—the type and form of the adhesive such as liquid or powdered urea, phenol, casein, or starch. These determine the basic characteristics of the adhesives and how they will respond broadly to conditions of use.

Environment—the wood species and the manner in which it has been prepared for gluing, the topography and the proximity of the opposite sides of the joint, the cleanness of the surfaces and the attractive forces free to unite with those of the adhesive.

Climate—the moisture content of the wood, the temperature and the pressure applied.

Nourishment—the solvents, fillers, fortifiers, and dispersing agents added during mixing.

Stimuli—catalysts, heat, and plasticizer.

Demoralizing Influences—the dirt, grease, wax, deposited on wood surfaces prepared for gluing, contaminants and extenders placed in the adhesive, faulty equipment for spreading and pressing.

Disease—polymerization or breakdown of the adhesive during storage and during its pot life. Improper mixing i.e. lumps, weighing errors, loss of solvent during spreading, precuring or drying before pressing, bleed-through, squeeze-out.

Death—the degradation due to moisture, heat softening, corrosion, and fungi, the stress imposed on the joint as a result of shrinking and swelling of the wood.

It is seen that an adhesive, in forming a complete bond, must go through several life processes under varying environmental conditions. Since most of the growth of an adhesive bond occurs under the guidance of the user, it is understandable why adhesive manufacturers usually refrain from guaranteeing satisfactory results from the use of their products. It therefore falls to the user to learn how to control the behavior of an adhesive and obtain full advantage of its properties.

The Structure of a Bond

In maturing to a strong bond, the adhesive must develop full strength in five different areas, each calling for a specific action by the various components of the adhesive. Weakness in any one area means loss of strength of the entire bond similar to the weakest link in a chain. Regarding these areas as links they are:

1. The wood and its inherent structural condition on one side of the joint.
2. The interface between wood and adhesive on that side of the joint.
3. The glue film.
4. The interface between wood and adhesive on the other side of the joint.
5. The wood and its inherent structural condition on the other side of the joint.

The Adhesive Film

The center part of a bond, most easily recognized, is the adhesive film. Its strength accrues somewhat from hereditary characteristics imparted by virtue of its composition. These involve primarily the cohesive forces which hold the material together, and which must therefore be strong enough to hold the wood members together. Oddly enough the thinner the adhesive layer, the stronger it is likely to be. The environmental condition of proximity of the surfaces, previously mentioned, therefore influences strongly this characteristic.

One of the sources of weakness of this part of the bond is air bubbles. These usually arise in the mixing and spreading operation as the result of beating or cleaving air into the mixture, and as a result of dissolving action on powders. If they are allowed to remain in the glue line while the adhesive hardens, the strength is proportionately reduced. The only means of removing air bubbles from the glue line is by the pressure applied to the assembly. Hence pressure, listed under climate, is one of the forces which promote the solidarity of the adhesive film. It follows therefore that *the presence of bubbles in a cured glue line is evidence that it has received insufficient pressure.* While this is often a feature of microscopic dimensions, it does provide a clue to the history of this factor in the life of the bond.

At this point it is well to consider the total work done by pressure. Not all the pressure applied to an assembly reaches the glue line to function as described above, and to perform several other duties of benefit to the adhesive such as aiding in penetration. The pressure applied to an assembly is consumed in four different ways:

1. To overcome friction in the moving parts of the equipment.

2. To bend the wood members into juxtaposition.
3. To compress high spots on the joint surfaces.
4. To impose a hydrostatic pressure on the adhesive film.

Only the fourth component participates in the behavior of the adhesive, and since this fourth component is the last to develop in a normal gluing procedure the others must first be satisfied. An observation therefore that indicates insufficient pressure on the adhesive film must direct suspicion not only at the amount applied to an assembly as registered by the pressure gauge, but also to the possibility that the press may be out of adjustment, that the joint surfaces may be uneven or poorly machined, or that the wood may be badly warped. It is often possible by a series of observations to deduce where the pressure has gone, particularly when one of the components has predominated. For instance, if it is observed by the solidity of the glue film that the fourth component has functioned along one entire side of a lumber edge-joint and not at all upon the other side, then the joint edges were probably machined out of square. Similar considerations indicate whether there has been a moisture change after machining or whether the surfaces were unusually rough. When pressure has been improperly applied through faulty mechanism, defects will appear consistently in certain areas.

Bubbles in the adhesive film also develop in edge-gluing with electronic power. This is due to the very rapid rise in temperature which not only expands the entrapped air but also vaporizes glue water. The concomitant rapid curing of the adhesive does not permit the escape of these air pockets and they remain in the glue line. The end point of this process may often be visible to the unaided eye as a frothy mass in the joint and should be regarded with suspicion.

Extenders which have been added to cheapen an adhesive mixture are another source of weakness in the adhesive layer. They impart no adhesive properties but dilute the adhesive and render it not only less capable of tolerating certain environmental conditions during its growth into a bond, but also render it more susceptible to destruction during its service life.

Much has been said about thick glue lines. Yet no one knows what is the permissible thickness of glue lines for wood constructions. There is some justification for the thought that the thickness of the adhesive film is of less importance than the lack of pressure which caused it, because associated with thickness are all the evil influences which make for weakness, such as poorly fitting joints, rough surfaces, and eccentric clamping. It may perhaps be stated that there is no maximum thickness allowance covering all uses but rather a dependence upon the type of adhesive and the nature of the construction. In some constructions as for example aircraft propellers and laminated bowling pins, any readily visible thickness may be too great. On the other hand, mortise and tenon joints, spline joints and low grade plywood often have glue lines one to several hundredths of an inch in thickness.

In any case it is good practice to distrust all glue lines which are greater than 0.010 inch in thickness, particularly if there is considerable variation present and more particularly if there are voids in the joint. Measures taken to reduce glue line thickness will usually result in improved performance of the adhesive.

The Interface Between Adhesive and Wood

Having considered the characteristics of the adhesive film, some thought may be given to the means by which it anchors itself to the wood substance. This is the most obscure phase of the bond. The complete theory remains to be developed and there is considerable speculation as to what actually takes place at this juncture. Two possibilities have been debated at great length, one involving the flow of the adhesive into the pores and interstices of the wood and upon setting, locking itself in place; the other involving chemical forces residing in the adhesive molecules and in the surface molecules of the wood which attract each other with great power. The former is termed mechanical adhesion since it is similar to a dove-tail type of fastening; the latter is called chemical (also specific) adhesion because of the chemical forces which are brought into action.

Both mechanical and chemical adhesion undoubtedly play an important role in wood gluing. They occur in differing degree in nearly all bonds, varying greatly in different types of adhesives and also within any one type depending upon use conditions. With some adhesives mechanical adhesion may be the major factor and with others chemical adhesion. Some use conditions favor the development of the mechanical part of the bond, others the chemical. One surface of a joint may have a strong chemical bond while the other is largely mechanical, the proportion being affected, for instance, by which surface was spread with adhesive, and the length of time elapsed before pressure was applied. With resin adhesives which are normally favorable to chemical adhesion, this action may be greatly inhibited by extenders, over-catalysis, excessively long assembly time and advanced age of the adhesive mix. Chemical adhesion is also greatly influenced by the treatment a wood surface has received prior to gluing. Burnishing by dull tools and sandpaper, excessive heating, dirt, grease and wax all reduce the chemical adhesion portion of the bond. There is a strong probability that the difficulty of gluing certain species of wood such as teak and heart gum stems from an incompatibility of these woods with the chemical type of adhesion. This action is closely associated with the wetting properties, later discussed, of both the wood and the adhesive.

It is often possible to observe when one or the other phase is predominating in a given bond.

Chemical adhesion is considered to contribute the major strength to a bond, and since it is sensitive to the environmental conditions mentioned, means of rapid evaluation of these factors would not only predict the integrity of the bond but might lead to the offending element responsible for the weakness.

The Wood

An adhesive bond owes a great deal of its apparent strength to the material being bonded. Many an adhesive has been condemned because of failure to take into account the effect of this factor. In addition to the boundary effects discussed in the previous section, the influence of this factor is evidenced immediately beneath the surface and in some cases throughout the lamination.

It is almost impossible to machine wood without injury to the fibers for some distance below the surface. Planers, which are considered to produce the best joint surfaces for gluing, may nevertheless cause considerable damage to the wood. The pounding of the knives and the shearing forces exerted as they pass through the wood, crush or otherwise deform the fibers beneath the cut. The extent of this deformation depends upon a number of factors such as species, grain direction, sharpness and speed of the knives, depth of cut, knife angle, and pressure of the feed rolls. Although a microscope is required to observe the ruptures produced, the fact that they occur in one plane, makes their effect cumulative in weakening a bond.

In sawn joints, rupture of the wood fibers at or below the surface is often much more severe because the cutting action is more in the nature of ripping or tearing. Veneer also is subject to weakness at the surface, particularly on the "open" side of rotary cut veneer. This results from the action of the lathe knife and nose bar. At the point where the veneer separates from the log, there is considerable bending and shearing across the grain which produces checks diagonally across, and extending part way through the thickness dimension. When this surface becomes part of a joint, it is likely to pull away from the rest of the veneer when relatively low stresses are placed on the bond in certain directions. Bethel and Huffman[4] have called attention to the erratic and unreliable results that can be obtained in conducting the plywood tensile shear test when notching of the specimen is done without considering the direction of these lathe checks.

The gluing of composition boards such as those made of chipped or fiberized material presents similar considerations since they are inherently rather weak in tension. Special care must be exercised in order to develop the greatest bond strength when any of these products forms one of the links of a joint. This is generally true in gluing most low density materials. It reaches great importance in the rapidly growing field of sandwich constructions.

When a bond is to be formed in an environment of weakness, the adhesive must do more than associate itself with the extreme surface elements. To do this is to invite the shallow fiber failures of the n'er-do-well bond. In order to purchase strength, the adhesive must infiltrate through and beyond the surface layers. By this action it accomplishes three things: (1) it reinforces the ruptured or otherwise weak area in the vicinity of the joint, (2) it obtains anchorage in the sounder material within, and (3) a varying depth of adhesive penetration serves to distribute stresses at different planes in the wood and thus delay their accretion to the danger point.

A final consideration with respect to the effect of the wood on the development of a bond: some adhesives are capable of destroying the wood they set out to bond. Certain chemicals incorporated in the adhesive for the purpose of stimulating or otherwise influencing its behavior may be injurious to wood and over a period of time may corrode and weaken this link in the joint. Adhesive manufacturers are continually on guard against such activity, however, since some service conditions encourage degradation of this type it is well to be aware of the dangers.

Wood also, is perpetually trying to throw off the grip of the adhesive. By its constant shrinking and swelling in response to changes in moisture content, stresses are created in opposition to the pull of the adhesive. There then develops the death struggle of the bond in which the severest cases involve compound effects of weakening of the wood by chemicals in the adhesive, weakening of the adhesive by atmospheric conditions, and loosening of the grip by shrinking and swelling of the joint. The evaluation of bonded constructions should therefore be conducted in such manner as to ensure the isolation of each effect.

The Development of a Bond

Having seen what an adhesive has to do and the environment in which it must function, it may now be observed how an adhesive goes about the business of forming a bond.

After the glue has been applied to the wood and the surfaces brought into contact, it must perform several actions, both physical and chemical, before a strong bond can result. It must (1) flow into a continuous film (2) transfer to the unspread surface (3) penetrate both surfaces (4) wet the wood substance at both surfaces, and (5) solidify to a strong mass.

In performing these actions the adhesive is merely attempting to get into all the little pores and crevices at both surfaces of a joint and establish as much grip as possible before the curing or drying process stops the activity. Note that the first three actions involve motion and consequently depend upon the mobility of the adhesive and all the factors that influence mobility. (The term mobility will hence-

[4] Bethel and Huffman, Influence of Lathe Check Orientation on Plywood Shear Test Results. Technical Report No. 1, School of Forestry, North Carolina State College, April 1950.

forth be used in referring to these three actions collectively). The fourth action depends upon a combination of mobility, chemical nature, and molecular structure of the adhesive and also upon the condition of the wood surface. The fifth action depends largely upon the compounding of the adhesive mixture and of course upon such climatic factors as temperature and moisture conditions which affect the rate and degree of hardening.

The extent to which each of the five actions has progressed determines to a large degree the quality of the resulting bond. Certain operating factors affect these actions and register on the glue line in characteristic patterns. In analyzing a joint, recognition of the adhesive pattern developed can therefore often lead to the answers to many gluing problems.

While an adhesive appears to have a number of complicated actions to perform, it functions methodically in performing them. that is, the actions occur in sequence. As curing of the adhesive stops or "freezes" the action at any point in the sequence, a definite pattern results. The patterns do however grade in either direction but this usually does not obscure the corrective treatment which may be necessary.

Flow

After an adhesive mixture has been applied to a joint and the pressure begins to increase, the glue flows and redistributes itself over the surface according to high and low spots and areas of greater or less pressure. This is the first action which must be accomplished and it requires pressure and contact by the joint surfaces while the glue is still in a fluid state. When an observation indicates that flow has not occurred, the diagnosis should be either that pressure was not delivered to the glue line at all, that it came too late, or that it came briefly and then was relieved. Further observation will often reveal which was the correct situation. If no pressure was delivered at all the joint will be open and the glue will be seen exactly as it was spread. If it came too late, the glue will be somewhat compressed at the high areas on the joint surface, and there will be occasional indentations made by the hardened glue on the unspread surface of the joint. In the case where the pressure came and went, the glue line will appear splotchy and irregular and some of the glue will be found on both surfaces.

There are also instances where the flow of the glue may be excessive and this can result in the familiar "starving" of a glue line by "squeeze-out". Starving by squeeze-out is most likely to occur where joint areas are narrow in one or both directions such as in edge-gluing of veneer or lumber. Diagnosis of this condition may lead either to the deduction that pressure was delivered too soon on those glues which require some assembly time, that the pressure itself was excessive, or that the glue was mixed too fluid. Since it is difficult to determine (by the appearance of the glue line) which situation existed, it is necessary in this case to have specific advance knowledge in order to deduce the cause of the poor performance.

Transfer

At the same time that flow is occurring, the adhesive should also be transferring from the spread to the unspread surface[5] since this action, like flow, requires that pressure and contact take place while the glue is still fluid. However, transfer does not always accompany flow. When the glue has hardened to a certain degree before pressure is applied, it may still have sufficient fluidity to flow into a film but will have lost the tackiness with which it is attracted to the opposite surface. This is familiar as the "chilled" joint that sometimes develops when hot glues are used on cold stock.

Penetration

After flow and transfer have been accomplished, the adhesive should begin to penetrate into the pores of the wood. In order for this action to occur, the previous two must first have taken place and again, pressure is the major activating force coupled with a suitable fluidity of the adhesive. Penetration is an important action, the control of which is one of the critical points in a gluing operation. The criticalness arises from the necessity for some penetration to occur in order to achieve deep anchorage but not so much that the glue film itself is depleted. Hence for each species of wood with varying tendency to absorb glue there is an optimum fluidity which will permit this factor to operate at its best. A major point observed during compounding of a new adhesive formulation is the ease with which its penetration characteristics can be adjusted.

The degree of penetration observed, from one extreme which causes "starving" to the other which produces a shallow bond, reveals a number of useful clues to the functioning of the adhesive. Overpenetration is brought on by excessive fluidity, by insufficient catalyst which reduces the rate of cure and prolongs the fluid period of the adhesive, failure to observe minimum assembly time recommendations during which the glue might thicken and prepare itself for the application of pressure, by lack of fillers, and by high moisture content of the wood, particularly in hot pressing operations. Shallow penetration is caused by the reverse of these factors.

The actions just described involve motion of the adhesive en mass. Observation of these actions is greatly facilitated if the glue begins its movement from a fixed pattern such as the series of ridges or ribbons which results from spreading with grooved

[5] It is common practice to apply the adhesive only to one surface of a joint. In making observations on glue lines, the most definite characteristics are found on the unspread surface since the adhesive arrives and functions there mainly in response to conditions of the operation.

rollers or scrapers. The spread pattern then provides a convenient point of reference for future comparisons. Spreading in pattern has other advantages which will be discussed later.

Wetting

Through the actions of flow, transfer and penetration, the glue has produced a film in contact with both sides of the joint and has diffused into the wood. This is as much as is required to form a strong mechanical bond when hardening occurs. Its chief strength is in shear, similar to a spline joint, but it may be similarly weak against other forms of stress such as tension. In addition to locking itself in the pores of the wood, the glue must now also grip the walls of the pores by means of chemical fastenings. The action that makes this grip possible is the wetting action of the glue. Wetting is a chemical term referring to the attraction of a solid for a liquid with activity between the molecular forces of each substance.

These molecular forces evidence themselves through the polar properties of the materials involved. However, of extreme importance to the art of gluing is the fact that the forces responsible for wetting and therefore for the achievement of the chemical portion of the bond, vary widely according to the treatment the wood surfaces have received and according to the condition of the adhesive at the time it must make contact. Much of this variation occurs at the hands of the user.

The underlying principle in the variation found in degree of wetting is that all materials which exhibit strong attractive forces at their surfaces become readily contaminated or otherwise tend to decrease their surface energy by any means available. All that has ever been said or written about the necessity for keeping surfaces clean and free from dirt, grease, dust and wax prior to gluing is aimed at improving the environment for the adhesive to best perform the function of wetting.

The wetting action of adhesives is easily inhibited. Excessive heat such as that produced by hot platens, dull planer knives, and worn sandpaper render wood surfaces unfavorable for wetting. The adhesive itself may also become less inclined to wet through the operation of several factors such as long open assembly times which permit the formation of a "skin" over the surface of the spread adhesive. With synthetic resin adhesives particularly, the age of the material both in storage and in the mix hopper lessens the ability to wet.

Solidification

If the actions of flow, transfer, penetration and wetting have progressed to the optimum degree, hardening of the adhesive to a solid mass should produce a strong joint. Hardening, curing, setting, drying, solidifying and polymerizing are all terms used in reference to the development of strength by an adhesive. The mechanism by which this process is accomplished varies between the different types of glues. Some harden by cooling, by loss of water or other solvents, by chemical action, or by combinations of these. The concern of the user toward this function centers on making certain that it can proceed to completion. For instance very thin veneer stock or piles which are impervious to water such as plastic overlays, will retard the strength development of glues which harden by drying. Low temperatures will inhibit the hardening of synthetic resins since they undergo chemical reactions. Conversely the hardening may be hastened by appropriate manipulation of the governing factor.

The Identifiable Characteristics of a Bond

Since hardening stops further motion of the adhesive, the development of a bond may be arrested at any stage in the process. Depending upon the extent to which it performed its duties and also upon the physical state of the adhesive when solidification occurred, certain characteristics will be imparted to the glue line.

The point to remember is that the adhesive actions begin with flow and end with solidification. Solidification of the glue can arrest the sequence at any point because each successive movement requires a finer degree of mobility for optimum results. By finer degree of mobility is meant activity of the glue molecules as against the mass flow of the glue mixture. Since wetting is the last action that occurs and needs the finest degree of mobility, it is always the first action that may be inhibited by the premature drying or curing of the glue.

The Four Types of Glue Lines

Depending upon the movements a glue has made between the time of spreading and hardening, it will assume one of four basic glue line types which are of important diagnostic value.

Type No. 1—Starved. When there is insufficient glue on the glue line to form the center link of the bond it is considered starved. The condition results from excessive flow or penetration or both or deficiency in the amount of glue spread. In appearance, the chief signs are absence of a glue film and open pores in the wood surface as if the glue had been sucked in without filling them. Often, if the glue has been spread in pattern, failure of the ridges of glue to meet as they flow together is evidence of starving.

Type No. 2—Bonded. This condition results when all movements have presumably occurred to the optimum degree; good anchorage to both surfaces, good reinforcement below the surface and high wood failure in tests. Under the microscope the glue is seen to have filled all the pores at the surface and for some distance within. The glue film itself will be solid and free from air bubbles, with no voids between the glue and the cell walls of the wood.

Type No. 3—Unanchored. In this condition, a solid glue line was formed by adequate flow and some penetration, but two factors may have combined to prevent the wetting action from establishing a grip. Either drying and curing rendered the glue unable to carry out this action, or the wood surfaces due to deactivating effects previously mentioned, have become unreceptive to the attractions of the glue. In either case the appearance of the glue line as viewed after rupture will present a replica or cast of the opposite surface, usually the unspread surface. This might be termed lack of transfer, but the opportunity for transfer was there and passed, since some penetration occurred. The process had reached the stage where wetting for proper anchorage should have taken place.

This is a treacherous condition because the bond does have some strength particularly in shear and does resist exposure to continuous conditions. Its main weakness is in tension and in resistance to alternating exposure conditions.

Type No. 4—Precured. The precured condition is the one most easily recognized. In this case solidification progressed to such a degree before the joint could be brought under pressure that all of the movements of the glue have been inhibited, including flow, the most agile. The spread pattern has not been obliterated except at high spots on the surface where maximum pressure developed.

It is in diagnosing this condition that spreading the glue in pattern is particularly helpful. Some people may be hesitant to assemble a joint when the surface is not completely covered with a layer of glue. However this should engender no fears if the spread is uniform across the surface. If the adhesive does not have sufficient mobility to flow together (one of the easiest actions) and fill in the spaces between the ribbons of glue, it does not have sufficient mobility to perform any of the other more difficult actions which are necessary to produce a good bond.

The Five States

In addition to the four types created by the disposition of the adhesive on the glue line as a result of motion or lack of it, there are five recognizable states into which the adhesive may develop during its fluid stage. These involve texture, final composition, and degree of hardening. They are difficult to describe and while some may be observed by eye, others require the microscope or some exposure test for identification. Their use in on the spot diagnosis is therefore limited and in any case is not recommended except after long association with and complete knowledge of the history of the patient, the adhesive.

State No. 1 Frothy. As the name suggests, the glue line appears foamy or full of air bubbles.

State No. 2 Grainy. This is a glue line which appears sandy or granular, as though the adhesive had not dissolved completely in mixing.

State No. 3 Filtered. This condition arises only with compounded glue mixtures in which one or more of the ingredients has fled the glue line by filtering into the wood. It is a special case associated with the starved type of glue line. Sometimes, due to the fact that it may have some strength, it is difficult to identify except by strength test after exposure to mild deteriorating conditions.

State No. 4 Solid. This is the state for maximum strength. There are no voids in the glue film. It is continuous from surface to surface and from edge to edge with all its ingredients in intimate association.

State No. 5 Undercured. Insufficient drying or curing has occurred to produce maximum strength and durability. This is often a question of degree, the more obvious cases being observable by stripping off the veneer or pulling apart a joint and noting whether the glue is still soft. When the glue has developed some strength, particularly the synthetic resins which hardened by chemical action, it is necessary to make exposure tests in order to determine whether curing has progressed to a suitable point.

The Diagnosis and Treatment of Glue Line Disorders

The cry is often heard that synthetic resin adhesives are difficult to use. This is true, if difficulty is judged by the need to exercise above average control over an operation. It is also true that a particular urea formula may tolerate comparatively narrow use-conditions, but the opportunity to alter the properties and hence to improve the tolerance is unlimited (except for curing at low temperatures). This makes the synthetic resin adhesives adaptable to a wide range of circumstances. Of perhaps greater advantage is the fact that bonds made with these adhesives and to a lesser extent those made with natural adhesives, will practically tell you what is ailing them, if you are conversant with their sign language. It is easy, for instance, to read in a glue line that the pressure came too little or too late, that a little more catalyst is needed to stimulate faster maturing, or that the climate i.e. moisture content, was disagreeable. Like any foreign language, however, the interpretations are vastly improved by previous knowledge or history of the situation. For example, if a glue line says it is starved, knowing in advance whether enough glue was applied would permit attention to be directed to learning where the glue went. The clarity with which a glue line registers its symptoms is also improved by applying the adhesive in a ribbon pattern so that slight movements may easily be detected.

In order to assay how well a gluing operation is being conducted as far as the performance of the adhesive is concerned, observations are needed which provide instant answers. Two methods are suggested, one analyzing the characteristic types and conditions which the glue line assumes in response

to certain operational irregularities, the other involving the functioning of the equipment.

Listening to the Glue Line

As indicated in an earlier section, glues must go through an optimum amount of certain movements in order to form a good bond. Too much or too little movement will result in weakness. It was shown that a progression of characteristics develop as a result of too much mobility at one extreme to too little mobility at the other, and that the best bond was formed somewhere in between. It was also shown that some operational factors influence mobility toward one extreme and some toward the other. This suggests that the progression may be shifted in either direction by merely playing one factor against another. For example, excess penetration of the adhesive brought on by a very porous wood can be counteracted by increasing the assembly time to allow some thickening before pressure is applied.

This entire procedure is based upon recognizing in which direction a shift of properties should be encouraged and knowing which factors will bring about the desired shift. Usually, dry wood, long assembly times, extra catalyst, higher consistency of the glue, extenders, and fillers will reduce mobility; and wet wood, short assembly times, porous wood, high pressure, and low consistency will increase the mobility. With this simple equipment we are ready to tackle the first symptom.

The starved glue line. This condition is caused by too much flow and penetration of the adhesive or insufficient adhesive applied. Therefore the first step in tracing the causes of the symptom is to ascertain whether enough glue was spread. This can readily be done when the adhesive has been spread in a ribbon pattern. If the ridges have been flattened down by the pressure on the joint, but have failed to merge, then there was not enough glue applied. If they have merged but have left unfilled pores on the surface, there is strong likelihood that too much glue has been lost by over-penetration or by overflow.

Starving by over-penetration is most frequently found in hot-press plywood due to the temporary extreme mobility of the glue brought on by the temperature increase. The condition is accentuated by high moisture content of the veneer and for this reason is often associated with so-called "blisters". What happens is that the adhesive is induced to leave the joint area by the heat and moisture present, and neglects to first form a bond. The heat then drives the moisture to a weak spot between the plies. Further heating creates steam pressure in this area which raises the blister when the press is opened.

Several treatments for this condition are at once evident: (1) reduce the mobility of the adhesive, (2) reduce the moisture in the veneer, and (3) reduce the temperature. The mobility of the adhesive may be reduced in three ways. (a) Increase the assembly period in order to allow time for some drying of the adhesive to occur. How much to increase the assembly period is a matter of cut and try, with limitations imposed by space and equipment. The period may be extended until signs of precure begin in develop at which point it should be cut half way back to the original assembly time in order to be at a safe operating level. (b) Increase the catalyst to speed the rate of curing and thus shorten the length of time the adhesive is in the high fluidity stage. This has limitations in that mixes must be made smaller and more often since the pot life will be shortened. (c) Reduce the amount of water in the glue mix as far as is practicable with the spreading equipment available. Since this has the effect of raising the solids content of the glue mixture (and also the cost) a lower spread may be applied.

Starving by over-flow, excessive squeeze-out, occurs mostly on narrow or otherwise small glue areas such as lumber edge-gluing. In this construction the applied pressures on the glue are likely to be great and the distance to the edges so short that the glue is inclined to escape rather than stay in place. Resin glues, due to their greater mobility, usually suffer more from squeeze-out than the heavier-bodied proteins and starches. A large share of difficulties encountered in the use of electronic presses arise from this cause. In other words, the glue line may be placed at a disadvantage before the electronic power is even turned on. The loss of more glue by penetration due to the heat generated in the glue line then completes the starvation.

Again the treatment is obvious, increase the body of the glue by reducing the amount of water. Another method which is perhaps more effective but less feasible due to interference with rapid production, is the practice of double spreading (that is applying the adhesive to both sides of a joint) and then allowing 10 to 15 minutes closed assembly time before pressing. This insures good wetting in addition to reducing the flow properties of the adhesive.

The precured glue line. As the name implies, a precured glue line is one in which the glue had cured or dried before pressure could be applied to induce the various movements. This is curing without pressure and the causes can easily be deduced. The most common cause is exceeding the assembly time beyond that recommended by the adhesive manufacturer. During this time, the glue may either cure or dry out to the point where it will not move when and if pressure is applied. Again spreading in pattern makes instantly and clearly visible whether pressure was applied and if applied whether it was uniform.

Usually some compression of the glue ribbons will occur. If this compression is uniform over the joint area, then the pressing apparatus may be considered satisfactory and the only correction that is necessary is to shorten the assembly time. If the compression is not uniform, and particularly if there

are bonded and precured areas in the same joint then there is trouble in the press or in the assembly.

In the section on the structure of the glue line it was noted that certain observations on the solidity of the adhesive layer would reveal the history of the pressure factor. When the pressure mechanism is the cause of the difficulty, evidence of precure will often appear consistently in a particular location and this can be checked by some means of marking on the assembly its position in the press. If a large percentage of precured glue lines begin to show up at one end of an assembly or plywood panel, a thorough investigation should be made of the pressing setup to determine whether the rams are all functioning, whether the press head of platens are warped, or whether something in the mechanism prevented the proper application of retaining clamps. In one such investigation for example, it was determined that in laminating a long assembly, the strain rods of the press prevented the end clamps from being tightened sufficiently.

Moisture changes in lumber which has been machined for gluing will also develop localized symptoms of precure. In this case however, both ends, or the entire edges or center area of the joint in the more severe situations, will be affected.

Random areas of precure (in contrast to localized areas) in laminated or edge-glued lumber are almost certain evidence of faulty machining.

Warped lumber may develop symptoms of precure in the glue line. Its chief effect however is to cause uneven pressure rather than lack of it since the force necessary to straighten the warp will be subtracted from one point and added to another.

Several causes of precure arise in plywood manufacture in addition to overly long assembly time. One of these which is easily diagnosed is the thin veneer edge-glued to thicker neighbors. In this case the boundary of the precured area will be sharply defined coincident with the edges of the thin veneer. The treatment of this cause is comparatively easy if the will to do so is instilled in the workers. Splicer operators soon become accustomed to the feel of the thickness of veneer being spliced. Veneer that is 0.005 inches thinner or thicker than normal is readily sensed and should be discarded.

In hot-press plywood, a frequent cause of precure is slow loading and closing of the press. The first panel to be loaded must reside on the hot platen until the others have been loaded and pressure has been applied. During this time the heat of the press may induce sufficient hardening of the glue to render it immobile. That this is the cause may be positively determined by numbering the openings of the press and transferring this number to the lower platen side of the plywood taken from each opening. The severest cases of precure may then be traced to a particular opening. Further substantiation is derived from noting that the glue line nearest the bottom of the opening is consistently worse than the other side.

When precure is due to this cause, certain loading aids are mandatory. These include metal or plywood cauls on the bottom and preferably on both sides of the assembly, rods to support the center of long panels as they are being lifted to the opening, and finally a hydraulic lift to raise loading truck and workmen nearer to the upper platen. Automatic loaders are helpful in a smooth functioning operation, but have been found cumbersome in eastern plants where plywood sizes vary and where production demands do not warrant their use.

Often, in order to shorten the pressing time of a resin adhesive, operators are encouraged to increase the amount of catalyst. This always increases the probability of precuring. Extreme vigilance must therefore be exercised when such "fast" mixes are being used.

The spreading of hot veneer is a frequent cause of precure with resin adhesives because extensive polymerization can occur before the panels are loaded in the press. Truck loads of veneer require at least a full day after drying in order to arrive at a safe temperature. When production scheduling does not permit this cooling period, the only recourse is shortening the assembly time to near zero.

The unanchored glue line. Since the unanchored glue line is caused by lack of wetting, the suspected factors are those which influence the molecular behavior and mobility of the adhesive and those which affect the purity of the joint surfaces. Pressure and spreading irregularities are beyond suspicion because of the occurrence of some penetration and flow which could not have taken place without pressure and sufficient glue spread. Whether the fault lay in the adhesive or in the wood surface is however difficult to determine without a complete history of the particular bond.

Considering the factors which have contributed to the delinquency of the adhesive in refusing to associate with the wood, the one most easily understood, arises from long open assembly times, particularly when the spread adhesive has been exposed to drafts from open windows or heating fans. A "skin" forms on the extreme surface of the spread adhesive under these conditions, similar to the "skin" that forms on paint or on hot milk. This "skin" has very feeble adhesive properties and coming as it does against the unspread surface of a joint, can block the wetting action. An obvious remedy is to avoid long open assembly periods. However, sometimes it is necessary in certain constructions to spread a number of pieces before assembling them. Difficulties may be avoided in such cases by applying the adhesive in widely spaced ridges rather than in a smooth film. Three actions thus counteract the effects of skinning: Less water is drawn from the glue by the wood, less glue surface is exposed to the air, and the skin breaks when pressure is applied, flowing fresh glue over the wood between the ridges.

Glues which are too old either in storage or in the mix, often lose their power to wet wood. In the case of resin glues this is because the continued polymerization has made the glue particles too large for effective orientation. Adhering closely to manufacturers' instruction in the storage and the maximum pot life of the glue will ensure that this factor does not operate.

The amount of curing or hardening that occur before the glue makes contact with the wood substance, subtracts from its ability to wet. The glue becomes like putty or plaster of paris, though retaining some life and the ability to move somewhat. It is to be expected therefore that, the same factors exclusive of pressure, which cause precure also cause unanchored glue lines except in the latter case the disease has not progressed to the final stage. Consequently this type grades over into the early stages of precure and the same treatments are indicated though of less drastic magnitude.

When the cause of unanchored glue lines is failure of the wood surface to provide a favorable environment in which the chemical forces of the adhesive might become attached, we are largely at the mercy of ignorance. It is readily understandable how dirt, grease and wax on the wood surface could deprive the glue of its chance to grip. However the exact reason for the refusal of some wood species to accept certain glues is not known. Nor is it known why burnishing by direct heat or by dull tools deadens the desire of the wood to embrace the adhesive. Observations at the present time indicate that alkaline types of glue are somewhat better able to break down the resistance to adhesion offered by such wood surfaces.

The frothy glue line. This condition grades from the meringue like frothy mass that is sometimes found in lumber edge-joints cured with electronic power, down to the occasional bubble that fails to get squeezed from the glue line. The main evidence to be derived from this condition involves pressure effects since pressure is the factor which is responsible for eliminating bubbles from the glue line. In the section on the structure of the glue film the manner of drawing deductions from this observation was presented. The same reasoning is used as for the relationship of pressure to precure, except that in this case the observation may be made even though flow has taken place and obliterated the spread pattern.

When the frothy condition is associated with curing by electronics, the temptation is to regard it as being caused by this method of curing the adhesive. Actually the condition already existed and the process only makes it more visible. This is done by expansion of the air in the bubbles. Localized areas of low pressure and thick glue lines are at the bottom of the difficulty.

The filtered glue line. One of the more difficult symptoms to observe, the filtered glue line gives important evidence to the adhesive manufacturer for it tells him how well the ingredients remain together and act as a team. All the ramifications of this disorder are beyond the scope of this paper. Two effects will be mentioned to illustrate the action involved.

This condition occurs most frequently and noticeably with extended resin mixes of the hot press type. (It is not as noticeable with cold press adhesives). Under certain situations of slow curing and high moisture content veneer, a high percentage of the resin portion of the formula will filter from the glue line and penetrate into the wood, leaving the extender behind. The glue line therefore is largely extender, and the bond may have some strength dry but none wet. It is actually a glue line which is starved of resin. The treatment therefore is the same as for the starved glue line.

Fortified hot press glues also sometimes behave in this manner. Urea glues fortified with melamine often do not give the durability expected. There is some evidence to indicate that the melamine in this case filters out of the glue line and leaves the urea substantially unfortified. Again considerable improvement can be obtained by treating for the starving condition.

The grainy glue line. The grainy glue line usually points to poor storage conditions during which the adhesive becomes less soluble. An additional cause of a grainy glue line is incompatible extenders. It also results from incomplete solidification and in this case has been found to exist where glues which harden by chemical action are used under conditions which promote rapid drying of the liquid adhesive. Rapid drying conditions are encountered with excessively dry wood, below 6 percent, and with electronic edge gluing when split second curing times are sought. The respective treatments are to regard with suspicion glue which requires an abnormal amount of water above the recommended formula in order to produce a spreadable mix. Always submit a sample of extender to the adhesive manufacturer for evaluation. Resin adhesives must be specifically designed for dry wood before they can be used with any degree of safety.

The undercured glue line. Since strength and durability are most likely to be affected by undercuring, some tests are usually necessary to determine the extent of this deficiency. The early stages are easily recognizable by the ease with which joints are broken open soon after pressing. Often curing under pressure is only carried to the point where the strength developed is able to hold the assembly together until the process subsequently reaches completion.

With resin glues a high percentage of the ultimate strength is developed long before the ultimate durability is reached. Some exposure tests are therefore necessary to determine when maximum durability has been achieved.

The treatment of undercured glue lines are obvious; more time in the press, higher temperature or

more catalyst in the case of chemical hardening glues, and longer press time and drier wood for the glues which harden by drying.

Listening to the Equipment

In the previous section a means was suggested for determining, posthumously as it were, the cause of death of a bond. Information thus gained can be used immediately to save other bonds from the same fate. However, much can be done during the growth of a bond to observe how it is functioning and to improve its living conditions. When equipment is in good operating order, it will often tell when the materials are not right; conversely when the materials are up to specifications, they will tell when the equipment is not functioning properly. For example, if a well adjusted spreader does not spread glue evenly it has said that the veneer is poorly cut, perhaps having thick and thin areas. Blisters in hot pressing say that the assembly is too high in moisture content.

Storage room. A brief trip through a gluing operation will illustrate the type of information that can be obtained by casual observation. Beginning in the glue storage room the prime consideration is that this area should be cool and dry. Heat and moisture are the enemies of most glues, particularly the resin glues. Rust on the inside rim of the lid of steel drums used for powdered resins is a sign that moisture has gotten in. Lumps, or sandy texture to the powder confirms the presence of moisture.

Mixer. In the mixing room, the operator should become familiar with the sounds the mixer makes as it goes through the various stages of the mix toward the final product. The pull of the motor, the grinding of the gears, the sloshing of the glue against the paddles and the height the glue is thrown up the sides of the mixer, all become characteristic for a given quantity and formula of glue. The placement of an ammeter on the mixer motor might help translate some of these observations into figures.

When the mix is emptied into the hopper, the presence of lumps in the mix or a sludge at the bottom of the mixer is evidence of improper mixing. Lumps are usually formed because of adding too much liquid to the powder for the initial phases of the mix. Always mix as dry as possible, thinning to final consistency as a last step.

Spreader. The spreader is a good informant. As mentioned earlier, it will indicate when veneer is rough or non-uniform in thickness by refusing to spread it evenly. The operator must then be informed whether to discard the veneer in the interest of quality or use it in the interest of hopeful economy. In deciding to use the poorly spread veneer, it is usually rerun through the spreader for more pickup.

Often the glue on the spreader rolls will become dry and gummy at certain points. This is due to poor circulation of the glue along the rolls and the pickup of bits of wood and fibers from the veneer. The amount of glue applied from such points will be different from the setting. The use of a circulating pump between the hopper and the rolls is recommended to keep the glue moving. A common practice is to remove the end plates from one or both ends of the rolls and allowing the glue to continually fall back into the hopper as the pump stays ahead of the spreading.

The ease with which spreaders and mixers can be washed at the end of each working period is a mark of good operation. This involves only the presence of suitable drains and hot and cold water through a hose, plus sufficient time to do a good job.

Assembly facilities. Confusion and disorder between the spreader and the press often creates unfavorable conditions for the glue. In laying up a plywood assembly, if it is necessary to drag the unspread plies over the spread ones to get them in position, glue will be scraped from certain areas and this will initiate starving. The proper placement of veneer trucks and the use of supporting sticks when handling large sheets of veneer will improve this operation. The use of well designed lay-up jigs and stops can do much to shorten the assembly time when evidence of precure indicates that it is too long. These will also pay dividends at the trim saw by assuring two good edges from which to reference the cut.

Press. In cold pressing plywood several points may be observed with profit. The amount and distribution of the squeeze-out gives important information about pressure. If there is some squeeze-out around all edges of all panels the pressure may be considered sufficient, uniform and on time. If the first few panels at the bottom of the bale show no squeeze-out and the upper ones do, then the pressure was sufficient, uniform, but not on time. If all panels show squeeze-out on one or two sides but not on the others, the pressure is sufficient, on time, but not uniform. When there is no squeeze-out a subsequent investigation of the glue line will show whether there was sufficient pressure and whether it was applied on time.

The alinement of the cauls after the bale is under pressure will tell whether the tiers of panels between cauls are one over the other as they should be, or staggered. Adjacent cauls which bend toward each other indicate that the panels between them are out of line with the remainder of the bundle. This immediately deprives the ends of panels from three tiers of a portion of their pressure.

After the bale has been removed from the press with the retaining clamps secure, bending of the I-beams or of the head boards indicates loss of pressure at the points where the bend is greatest i.e. at the center of the bundle and midway between each I-beam. If subsequent examination of the glue lines shows evidence of lack of pressure at these points, the number of clamps on the bundle must be increased. In this case, since pressure at one time was

uniform (while in the press), the lack of pressure will register on the glue line with a splotchy characteristic.

In hot pressing plywood, a fast, smooth-functioning loading crew is necessary for continuous success. The speed of loading and closing the press are critical factors, the faster, the better. Once the panels are safely in the press, there are not too many factors which can interfere with the completion of the bond because from here on the operation is largely mechanical. The operator should however make certain that the temperature is maintained at the proper level and uniform in all platens and that the pressure gauge reading is correct for the size panel being pressed. The frequent occurrence of blisters is a symptom that is often treated at the press. As previously shown however, the cause is elsewhere. High press temperature contributes to the formation of blisters when other unfavorable conditions are present.

The edge-gluing and laminating of lumber also present characteristic points for observation. Throughout these processes, as in the gluing of plywood, the same considerations apply, viz, the necessity for the adhesive to perform certain functions, and the recognition of the factors which might prevent these functions.

In the foregoing discussion a method has been presented for looking at the gluing operation with some sympathy for the manner in which glues develop into bonds. It is hoped that this will result in increasing familiarity with the propensities of the particular glue being used and thus lead to improvements in conditions which will allow that glue to perform with greater satisfaction.

The language and terminology used in this paper are perhaps not altogether in accord with those usually employed in this field. It is felt however, that those most in need of the information would appreciate digression from precise scientific expression.

Discussion

S. S. Hunt (Monsanto Chemical): It is stated that air bubbles in glue are perhaps a dangerous thing. We know that the Germans used foamed glue during World War II. This meant that minute air bubbles were introduced into the glue mix by various means. By so doing they were able to spread the mix more thinly on the wood. Do you see any harm in the possibility of using air bubbles in glue?

Thomas D. Perry (Engineer): The use of a foamy glue obviously decreases the net amount of adhesive applied per unit of area. Hence for joints of maximum strength and durability, in a dense species, the use of a foamy glue would not be advised. However in plywood products where high quality is not essential, such as plywood box shooks that make a single trip without reuse, or in drawer bottoms or dust backs, where finish and wear are not significant, it might be possible to use a foamy glue even with a sacrifice in strength and durability. This is opinion only and not based on operating experience.

Mr. X: When an adhesive fails to anchor itself, designated as glue line type 3, does this not imply lack of compatibility of the wood surface and the adhesive? If so, how can anything be done in the gluing operation to improve the bond? It would seem that some other adhesive is necessary.

Mr. Perry: It is undoubtedly true that chemical compatability between glues and wood species, is more pronounced in some combinations than in others. However any standard glue is required to produce adhesion is commercially used species. There may be exceptions in woods containing oils or other unusual material. By and large, there should be no especial reason for selecting a special type of glue for a given species.

Mr. X: The paper suggests a system of observation and deduction which should help to determine whether the adhesive is being used correctly. Deductions usually involve a certain amount of guess work. Where would you set up watch-dog control points which might improve the validity of your conclusions?

R. F. Blomquist (Forest Products Laboratory): It is, of course, important to observe, check, and control all of the factors in gluing operations to be certain of consistently high quality joints at all times. To check only certain points and neglect others would be better than no control but could still leave the way open for some gluing difficulties. If only a few "control points" are to be used, the following are suggested:

(a) The glue when on the spreader (observe for unusual differences in consistency, colors, odors, and uniformity of spread when used). However, glue mixing also should be checked at least periodically.
(b) The condition of stock when ready for glue spreader (for quality of surfacing, degree of fit, etc.). This should include checks on moisture content of stocks.
(c) The panels after pressure is applied (for uniformity of glue squeezout, alinement of stacks of panels for uniformity of pressure, condition of press equipment, temperature of room, etc.).
(d) Condition of joints at cut-off saws or other trimming operations (include actual destructive knife or chisel tests on trim and observation of broken joints).

In addition, regular checks should be made on the mechanical condition of all equipment (mixers, spreaders, surfacing, tools, presses, steam lines, and conditioning chambers).

Mr. X: The paper infers that there is little choice between various adhesives. If handled correctly many of them will perform in a satisfactory manner. Does this mean it is possible to use any adhesive with equal success? In other words, what are the criteria for the purchase of the correct adhesive?

Mr. Blomquist: Generally each type of currently available woodworking glue can develop the strength of the wood (of even high density species) when properly used. This is as much as is required from the standpoint of dry initial strength. The conditions under which various types of glues must be used to give these high strengths may vary considerably for different glues and this is one factor in selecting a glue for use. In other words, some glues may require certain gluing conditions (cure temperature, assembly periods, temperature control) that are not feasible for certain plant operations and therefore can not be considered seriously. Another principal difference in the various types of glues is their durability characteristics (resistance of joints to water, moisture, heat, microorganisms, mechanical stresses, etc.). These durability characteristics have been well described and discussed in Forest Products Laboratory Mimeograph No. 1530. A third criteria is cost. This should, of course, include not only the cost of the mixed glue but the amount of spread required per unit area and any additional costs involved in use (labor, equipment, etc.). (labor, equipment, etc.).

Mr. X: Do you not believe that the various gluing pressures recommended for various woods are arbitrary figures such as 100 pounds for soft woods and 200 pounds for hard woods?

R. L. Hiller (American Cyanamid Company): To the best of my knowledge, such recommendations are not based on experimental data but were merely chosen as recommended pressures. It seems to me that it would be possible to get as good a bond at 5 pounds per square inch with the proper gluing conditions and stock. This would make an excellent subject for study and possible presentation of a paper at one of the Society meetings.

Methods of Controlling Glue Bond Quality

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The application of known quality-control techniques to gluing operations can promote higher and more uniform bond quality, reduction of waste, and more efficient use of labor and equipment. To be most effective, however, quality control programs must apply to all phases of the bonding operation including (1) the purchase of raw materials, (2) their pre-manufacturing preparation, (3) the manufacturing processes and (4) product testing to insure conformance to minimum standards. Specific methods of controlling within satisfactory limits many of the variables encountered in gluing operations, particularly as they apply to plywood bonding operations, are discussed.

Introduction

THE raw materials, equipment and processes used throughout the plywood industry are essentially very similar, and few manufacturers, if any, have special techniques unknown or unavailable to the remainder of the industry. Therefore, theoretically at least, the quality of a given kind of plywood should be roughly the same in all respects regardless of the manufacturing plant in which it originates. In fact, we are already well acquainted with the high level of product standardization attained among the members of the Douglas Fir Plywood Association. Why is it then that differences in quality do exist among the panels produced by various manufacturers in similar segments of the hardwood plywood industry? The answer, in large measure at least, lies in the differences in the degree of control over all those variables which affect the quality of the final product.

From an absolute standpoint, control over the quality of any manufactured product can only exist if all of the variables which affect the quality of the finished product are systematically controlled. However, when all of the possible variables influencing the conversion of raw materials through the application of labor, machines and manufacturing conditions are considered, it must be realized that such a measure of quality control can only be an ideal. On the other hand, between this maximum point and one at which there is no systematic control over manufacturing variables whatsoever, there exists a wide area in which the application of quality control techniques can result in an improved product, reduction of waste, savings in material and labor and a reduction in manufacturing costs.

The term quality as such has little meaning unless the end use of the product is indicated. Thus a plywood panel bonded with a highly extended urea glue may be of good quality and entirely satisfactory for such uses as dust bottoms or case backs but entirely inadequate for exterior applications. Similarly, the term quality has a meaning only when it is related to definable and measurable characteristics of the product involved. It is in this connection that standards and specifications enter the picture. Without them, a quality control system has no basis. For the purpose of this paper then the term quality will signify conformance to a given set of standards.

Any quality control system is based on the premise that imperfections in a product are caused by variables in a manufacturing process. At the same time it is quite obvious that absolute control over all possible variables in any manufacturing process is impossible to attain and costly to approach. Through systematic control over the more important variables, however, the overall effect of the many variables encountered can be minimized to reduce the imperfections appearing in the final product.

From the consumer standpoint, a product must be acceptable in regard to both quality and price. The customer is interested in obtaining the highest possible quality at the lowest possible cost. The manufacturer is primarily interested in getting the maximum profit from the application of his raw material, labor and capital investment. In between these two extremes is a zone of common agreement between the consumer and the manufacturer where quality meets minimum requirements and the costs of production are not prohibitive. In this connection, and with the notable exception of the Douglas Fir Plywood Industry, there is an overall lack of uniform standards applying to all phases of plywood quality that are accepted by both producers and consumers of plywood. There are commercial standards which supposedly apply to a large segment of the hardwood plywood industry and government specifications which have a more restricted application. However, "what the customer will buy" is usually the deciding factor governing the control of plywood quality in the industry today. Not only is there a lack of uniformity as to what different customers will accept but the standards vary with each customer, depending upon the forces of supply and demand and other factors in effect at the time each purchase is made.

Under the above circumstances the establishment of uniform standards for bond quality becomes the responsibility of the manufacturer. For this reason this paper attempts to point out how quality con-

trol techniques can be applied to plywood bonding operations to obtain uniform glue bond quality, reduced production costs, reduction of waste, and more efficient use of labor and equipment. From the outset, however, it must be accepted that control over glue bond quality cannot be obtained solely by inspection of the finished panel. Even if a defective bond is detected at this point, it is difficult to state whether the glue, the glue mix or any one of the many factors involved in the use of the glue mix was primarily at fault. Thus, control over the final quality of the bond must begin early in the bonding operation if it is to be effective.

A systematic control over the entire gluing operation would, of necessity, include the following:

(1) Checking the uniformity and suitability of the glue and other raw materials used in the glue mix. (2) Checking the uniformity and suitability of the glue mix. (3) Maintaining a satisfactory control over the important variables encountered in the gluing operation. (4) Checking the bonded panels for conformance to minimum standards of bond quality.

As quality control operations are essentially nonproductive in nature, their cost must be figured as indirect expense. Quite obviously a staff sufficiently large to maintain constant control over the above mentioned phases of quality control as applied to the gluing operation would become burdensome if not prohibitive. Therefore, after the initial quality control system has become established, it may be maintained by a system of spot checks, the necessary intensity of which can be accurately determined only through a statistical approach. The application of statistics to quality control programs is not new and considerable data has been published on this subject.[1, 2, 3, 4]

There are test procedures and methods available today by which almost every variable in the gluing operation can be measured and analyzed. The consistency of a glue mix can be measured in centipoises. The moisture content of wood can be determined in percent of its oven dry weight, and temperature in degrees F. However, these figures are of little value in themselves unless it is known what the optimum values should be for each type of glue, each panel construction and their acceptable limits, when the interaction of all variables involved in the gluing process is considered.

Thus because the glues used and the bonding conditions encountered vary so widely in all plants throughout the plywood industry, it is currently necessary for each manufacturer, with the help of his resin glue supplier, to develop his own set of limits for each of the variables in the bonding operation. He must also establish an initial quality control program to maintain glue bond quality based on his own specific requirements or desires.

This paper will be restricted to a discussion of quality control as applied to thermosetting resins as typified by the urea, melamine, phenol and resorcinol types, because of their widespread adoption by the furniture and plywood industries.

Raw Material Control

The types of resin glues available today, the forms in which they are available and the general quality of wood-to-wood bonds they are capable of creating are fairly well known and will not be discussed as such in this paper. It might be mentioned, however, that any of the commercially available resin glues are capable of producing bonds stronger than the wood itself when properly prepared and used under satisfactory conditions. Therefore, selection of a resin glue for any particular application should be made with a view toward bond permanence or durability under the most severe conditions to which the assembly will be exposed. Thus, for exterior exposure or marine applications, plywood bonded with phenol, resorcinol or melamine resin glues would retain its original bond strength whereas plywood bonded with a urea formaldehyde resin would deteriorate at a rate governed by the severity of the conditions encountered. On the other hand, urea formaldehyde resins have adequate strength and permanence for such application as furniture and interior decorative panels and in addition have relatively wide latitude in handling characteristics coupled with low cost.

Control over incoming raw materials used in the gluing operation not only insures the consumer that he is getting what he is paying for but demonstrates whether or not a given product has the required uniformity from batch to batch and is otherwise suitable for use in his specific bonding operations. Assuming that a given type of adhesive has been selected and is well suited for the bonding application involved, there are certain characteristics of the resin itself that have a definite affect on ultimate bond quality. Certain of these characteristics are:

(1) Chemical composition of the resin glue. (2) Resin solids content. (3) Fillers, modifiers, thinners and solvents. (4) Viscosity. (5) Age. (6) pH of glue line. (7) Reactivity (set-time). (8) Curing characteristics. (9) Latitude in respect to bonding conditions. (10) Catalyst. (11) Storage life. (12) Bond strength (cohesive and adhesive properties).

However, not all need be a direct concern of the plywood manufacturer if it can be demonstrated that the resin is uniform from batch to batch and will do the job for which it was intended. Therefore, if such properties as resin solids, viscosity, reactivity, and storage life are measured and found

[1] Bethel, J. S. Techniques in hardwood plywood quality control. Proceedings Forest Products Research Society. Vol. 4:162–169.

[2] Ferris, D. W. Statistical controls for dimension materials. Wood, August 1947.

[3] Ferris, D. W. Quality control formulas, tables, and processes in manufacturing veneer. National Hardwood Magazine, September 1947.

[4] Grant, E. L. Statistical quality control. 1946. McGraw–Hill, New York.

to conform to acceptable standards, the glue can safely be released to production. The proper limits relative to each of these properties may be obtained from resin suppliers.

There are in use today several methods of determining the proportion of resin solids or non-volatile matter contained in liquid thermosetting resins. One of these, ASTM Test Method D115–48T, is reproduced here. It will be noted that resins of the phenolic type are placed in constant-temperature ovens maintained at 132–138 deg. C. whereas, other types of varnishes, including urea resins, are dried in a similar manner at 105–110 deg. C. for such determinations. Determinations of the resin solids content of powdered resins involve much more complicated equipment and procedures and are impractical for most resin consumers to make. Then too, because of the nature of the product, such determinations are actually unnecessary.

NON-VOLATILE MATTER BY WEIGHT

ASTM Test Method D115–48T

Apparatus

The apparatus shall consist of the following:

(a) Chemical Balance.

(b) Thermometer. A glass thermometer having a range of 0 to 150 or 200° C. and accurate within 1° C.

(c) Oven. A constant-temperature oven.

(d) Bottle and Drying Dishes. A stoppered bottle and flat-bottom metal drying dishes. Each metal drying dish shall have an inside diameter of approximately 2¾ in. and a depth of approximately $\frac{5}{8}$ in.

Note: A standard single-friction tin can cover having a diameter of $2\frac{13}{16}$ in. is suitable for use as a drying dish.

Procedure

(a) Preparing Specimens. A portion of the sample of varnish shall be placed in a stoppered bottle or weighing pipette and weighed. A specimen weighing approximately 1.5 g. shall be transferred from the weighed stoppered bottle to a weighed drying dish which has previously been heated for 30 min. at 135 deg. C. and cooled in a desiccator. The stoppered bottle with the remaining contents shall be weighed again. The exact weight of the specimen transferred to the drying dish shall be determined by difference. A total of three specimens shall be prepared from the contents of the stoppered bottle.

(b) Drying Specimens. The specimens shall be placed in the constant-temperature oven within 30 min. after preparation. The specimens shall be heated for a period of 3 hr. at the temperature designated, as follows:

Impregnating varnishes of the phenolic-resin type 132–138 deg. C.

Other types of insulating varnishes 105–110 deg. C.

Note: In a gravity type of oven which depends upon the natural circulation of air for uniformity of temperature, only one shelf must be used for supporting the specimens, and the bulb of the thermometer for indicating the temperature shall be in close proximity to the specimens.

(c) Weighing Dried Specimens. At the termination of the 3-hr. heating period, the specimens shall be removed to a desiccator and cooled to room temperature. Each specimen shall be weighed immediately upon removal from the desiccator.

Calculation and Report

(a) The percentage of non-volatile matter by weight shall be calculated as the ratio of the weight of the dried specimen to the weight of the specimen in the original state expressed as a percentage.

(b) The report shall include the following:

1. Type of varnish tested.
2. Oven temperature and
3. Percentage of non-volatile matter.

Of the many methods available for measuring the viscosity of liquids probably the ones most adaptable for use by resin glue consumers involve the use of Parlin or ASTM Consistency Cups. These are available with orifices of several different sizes to accommodate liquids over a wide range of viscosities. Essentially, each method consists of timing the interval required for a definite volume of resin glue, which has been previously adjusted to a specified temperature, to flow through the orifice of the proper cup, and converting this figure to absolute viscosity readings by the use of Viscosity Comparison Charts of the type available from the Armour Chemical Division, Armour & Co., 1355 W. 31st St., Chicago 9, Illinois.

The reactivity of a resin glue is essentially a measure of its curing speed and as such is primarily of importance when applied to relatively rapid setting resins of the urea and resorcinol type. Although individual manufacturers of resin glues probably have specific tests well suited for use with their own resin glues, a simple method requiring little equipment involves only the addition of a specified amount of a standard catalyst to a known quantity of the resin, adjusting its temperature to a predetermined level, commonly 77 deg. F., and maintaining the mix at this temperature until it gels to a non-flowable state. The length of time required for gelation to take place would then be a direct measure of its reactivity.

Certain mixes of resin glue often require excessive periods of time to gel at 77 deg. F. Here the use of a home made oven that can be maintained at 140 deg. F. with little deviation will accelerate the gelling speed and reduce the time required to complete the test.

Fig. 1 represents a schematic drawing of an inexpensive, easily constructed oven which can be used for this purpose. The oven may be constructed of wood or metal and lined with asbestos or other insulating material. Temperatures in the oven are controlled by the number of light bulbs, their wattage and the amount of circulation permitted. The venti-

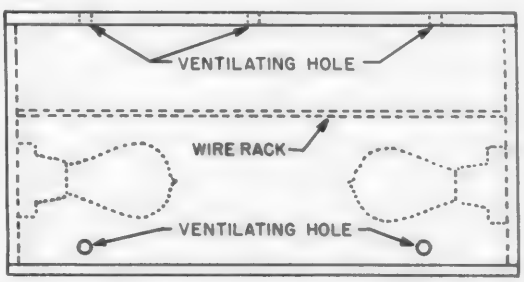

Fig. 1.—Schematic drawing of home-made laboratory oven.

lating holes should be provided with sliding covers so that the amount of circulation can be regulated. Of course, much more satisfactory ovens capable of very close temperature regulation are available from laboratory equipment supply houses.

The most practical method of measuring the storage life of thermosetting resin glues is through periodic measurement of its viscosity. When the resin has increased in viscosity to the point where it can no longer be used under normal production conditions, its storage life is said to have come to an end. As the aging characteristic of resin glues is directly related to the temperature at which the glues are stored, accelerated tests may be made by storing the test samples at 110 deg. F. rather than at room temperature. The actual values, however, are of no importance unless a correlation is made between the accelerated aging characteristics and the actual storage life under room temperature conditions for each material.

An oven similar to one used to obtain resin reactivity measurements but regulated to 110 deg. F., is satisfactory for such accelerated aging tests. Representative samples from each batch of resin received should be tested for storage characteristics. Quite obviously, glue should not be held in storage pending completion of tests on its storage life. Such data on aging characteristics are primarily important as a measure of the uniformity of the resin glue from batch to batch and also as a guide to the purchasing department in establishing an inventory control.

When plywood or other bonded wood structures are supplied on orders in which government specifications are involved, the problem is somewhat simplified. In some instances, government agencies test available resins themselves in their own laboratories and actually list those which may be used on certain government contracts. In other cases, it is specified that the glue used must meet the requirements of definite specifications. In this latter instance, it is usually the custom of the resin glue consumer to request from his supplier certification that the material supplied will meet the requirements of the specifications involved. Such certification may or may not be accompanied by actual test results on the material shipped. It should be emphasized, however, that any such notice of certification in this respect states only that the resin as supplied will meet the specification requirements and does not imply that finished articles made from it will conform to related process specifications.

Control over the quality of fillers, extenders, modifiers, thinners and other additives which are used with thermosetting resin glues is obviously important because of the direct influence they have on glue line quality. Of these additives, the one probably subject to most variation is wheat flour which is commonly used as an extender for urea resin glues. Although a definite type of wheat flour may be desirable for a specific application, either summer or winter wheat flour is suitable for use as an extender. However, an unbleached flour and one unmodified with chemicals such as those found in self-rising flour should always be specified. Once a flour gives the proper viscosity, spreading and handling characteristics, its gluten content, ash content and viscosity should be determined. Then future purchases can be made on a specification which will ascertain procurement of flour with similar characteristics. The object in this case is to purchase flour having similar characteristics from shipment to shipment and not necessarily to purchase the same brand each time.

The following form has been prepared as a suggested system of keeping records on each batch of resin purchased.

RAW MATERIAL CONTROL—RESIN GLUE

Resin Glue and Manufacturer _____
Type _____
Batch Number _____
Quantity Received _____
Date Received _____
Date samples taken _____
Resin solids content_____%
Gel time at 140° F._____minutes
Viscosity_____centipoise at 77° F.
Remarks or recommendations:
Tested by _____ date _____
Approved _____ date _____
Not approved _____ date _____
Remarks _____

Preparation of Glue Mixes

After a particular batch of resin glue has been released to production, three tests may be applied to almost any thermosetting resin glue mix to insure reasonably accurate control over the preparation of the glue for use. These are (1) viscosity, (2) gel time and (3) working life.

The viscosity of a glue mix has a definite relationship to its spreading and handling characteristics. Once the acceptable range in viscosity has been determined for each type of glue mix and bonding application, only reasonable care in mixing should be necessary to maintain a uniform viscosity from batch to batch. A procedure for measuring the viscosity of resin glue has been discussed previously. The same procedure may be used for measuring the viscosity of glue mixes. However, it is important to select a cup with an orifice sufficiently large to insure completion of the test within two minutes when making determination on resin glues extended with wheat flour. This will minimize errors arising from the thixotropic nature of such mixes. Since it is the temperature of the glue mix in use that will, in some measure, determine its working viscosity, it is probably not only unnecessary but undesirable as well, to adjust the temperature of the mix to a constant temperature before making viscosity measurements. If possible, the viscosity measurements should be made at the probable temperature of the glue mix in use.

A method for determining the reactivity of a resin glue has been suggested in an earlier section.

A similar method may be used to ascertain the gel time of prepared production mixes as a means of insuring uniformity from mix to mix. However, in this case, a sample of each actual production mix is maintained at a constant temperature until it gels rather than simply a mixture of the resin glue and a standard catalyst. Once adequate gel time limits are established, they may be used to guard against failure to add the proper catalyst in the correct amount and against contamination of the mix.

The working life of a mix is a measure of its usable life and may or may not be close to its gel time. The working life ends when the viscosity of the mix rises to the point where the rate of glue spread can no longer be adequately controlled without frequent adjustment of the spreader. For example, a freshly prepared glue mix might be spread at a rate of from 28 to 32 lbs. per 1,000 sq. ft. of single glue line area by a given adjustment of the spreader. As the age of the glue mix increases, the mix will gradually increase in viscosity until the rate of spread has gone beyond this range. When this occurs, the working life of the mix has been exceeded. A method of measuring the rate of glue spread will be discussed in detail in a later section of this paper.

If uniform batches of resin are to be prepared, precautions should be taken to insure that the proportions of resin glue, fillers, extenders, catalysts, and other additives recommended by the supplier are accurately weighed or otherwise controlled within close limits. Weighing and mixing equipment should be kept clean. Accurately calibrated volumetric methods are probably most satisfactory for measuring quantities of liquids. Whenever possible, powdered resins or flour should be used in unit-package quantities. Formulas for each glue mix should be carefully typed and placed in glassene envelopes and located in a suitable place near the mixing operation. The exact mixing procedure should also be included with each formula and its details carefully followed each time a mix is prepared.

Since control over the mixing operation demands the preparation of mixes with definite limits in regard to such properties as viscosity, gel time and working life, the possibility that the glue mix does not have the proper bonding characteristics is avoided. Thus the danger of producing large quantities of plywood with sub-standard bonds is greatly reduced.

Control Over Gluing Variables

The actual mechanics by which a bond between adjacent pieces of wood is produced with thermosetting resin glues can be broken down into several clear-cut stages for convenience in following the glue's action from the time it is spread until it hardens to form the final bond. After the glue has been spread on the wood and the mating surfaces to be bonded are brought into contact, the glue *flows* into a continuous film between the wood layers, *transfers* to the unspread surface, *penetrates* both surfaces, *wets* the wood structure and finally *hardens* into its final cured state. If the conditions which influence each of these five phases of bond formation are within acceptable limits, each phase completes its particular function and a strong, durable bond results. However, if one or more factors disrupts this exact sequence of steps, hardening of the glue takes place and halts the sequence.

The first three stages of bond formation depend upon the movement or fluidity of the glue mix. Fortunately, the factors governing these 3 phases of bond formation are well known and are subject to the control of the plywood manufacturer. The fourth stage, wetting of the wood substance, is a much more difficult phase of bond formation to define and is thought to consist of a linking of the wood substance and the glue through the medium of attractive forces which are normally found in each. The manufacturer has little direct control over this phase of bond formation, although he can promote the conditions which favor it by properly preparing the wood for bonding and by carefully mixing and handling the glue. The fifth stage, hardening of the glue, primarily depends upon the nature of the glue mixture and such factors as temperature and the amount of moisture at the glue line, which directly affect the rate of cure.

The factors which control the fluidity of the glue, its interaction with the wood substance, and finally, hardening of the glue are as follows:

(1) Temperature of glue room, (2) Temperature of glue mix, (3) Relative humidity of glue room, (4) Rate of glue spread, (5) Uniformity of glue spread, (6) Condition of glue spread, (7) Assembly time, (8) Pressure applied to assembly, (9) Temperature at glue line, (10) Species of wood, (11) Moisture content of wood and its uniformity of distribution, (12) Temperature of wood, (13) Condition of wood surface in respect to cleanliness and smoothness, (14) Random occurrence of heartwood and sapwood, (15) Number of plies, (16) Thickness of plies.

The details of the relationship of these factors to bond formation are discussed in the following sections.

Stock Control

The condition of the veneers at the time of gluing has a very definite influence on bond quality. While the species which are available for use, the random occurrence of heart and sapwood, and the individual gluing characteristics of each species are not subject to the control of the manufacturer, such factors as the moisture content of the stock, the occurrence of thick and thin veneers and the temperature and surface condition of the stock can be controlled within acceptable limits.

Theoretically, wood and veneers should be bonded at the equilibrium moisture content which

they will assume in actual use if flat, stress-free panels are to be obtained. However, this equilibrium moisture content frequently is hard to predict and is quite often outside the range considered optimum for best bond production. Then, too, other factors may control or prescribe the moisture content of the stock to be glued. It has been found from a practical standpoint that if the range in moisture content of the stock can be controlled within prescribed limits, other variables in the bonding operation can be adjusted to produce bonds of uniform quality. It can't be emphasized too strongly that an average figure representing the moisture content of stock to be glued is meaningless. For example, it is commonly recommended that a satisfactory average moisture content for cold press gluing stock in operations employing urea resin glues is 10 percent. Deviation from this average should not exceed plus or minus 2 percent and emphasis, therefore, should be placed on obtaining a satisfactory range of moisture content—normally 8 to 12 percent. However, it is not uncommon to have the moisture content of gluing stock vary from 2 to 20 percent and still have the average fall near 10 percent. Should this happen, however, results in terms of bond quality and panel flatness would be decidedly different.

Methods of drying veneer and lumber to fairly uniform levels of moisture content are well known. For best results, veneers are usually separated as far as possible by species, heartwood and sapwood and thickness and separate drying schedules prepared for each. However, unless veneers and lumber are stored under conditions of temperature and relative humidity which will maintain the proper moisture content limits until the stock is glued, the excellence of the original drying procedure is of little importance. In fact, during the winter months difficulty is often encountered in the bonding operation simply because the stock has continued to dry under storage conditions until it has less than the minimum moisture content essential for good bond formation. For example, assuming a constant relative humidity of 75 percent outside a manufacturing plant, the following table indicates the relative humidity and equilibrium moisture content of the wood stored inside the plant when the inside temperature remains at 72 deg. F. and the outside temperature varies.

Outside temperature deg. F. (Constant relative humidity of 75 percent)	Corresponding inside conditions when plant is maintained at 72 deg. F.	
	Relative humidity percent	Equilibrium moisture content—percent
70	70.1	13.0
40	23.5	5.0
30	15.6	3.6
0	3.0	less than 1
—10	2.1	less than 1

Control of the equilibrium moisture content of stock during long periods of storage can be accomplished by artificially humidifying the plant to the level necessary to sustain the moisture content of the stock at the proper level. The following table indicates certain relative humidity—equilibrium moisture content relationships at 70 deg. F.

Relative humidity at 70 deg. F.	Equilibrium Moisture Content—percent
10	2.5
20	4.6
30	6.0
40	7.6
50	9.1
60	11.0
70	13.0
80	16.0
90	20.8
100	31.0

The amount of moisture contained in wood has a major influence on the mobility of the glue during bond formation and, therefore, affects flow, transfer and penetration of the glue mix to a marked degree and affects the wetting of the wood substance and cure of the resin to a slightly lesser degree. Assuming that all other conditions influencing bond formation remain the same, variations in moisture content of the stock can produce bonds which vary from the starved condition at excessively high levels to a dry condition at excessively low levels.

The use of drying ovens and electrical moisture meters for the measurement of the moisture content of lumber and veneer is so generally understood that their use as quality control instruments will not be discussed here. However, moisture meters should be checked and adjusted by the manufacturer of the meter at regular intervals.

The condition of the stock in respect to uniformity of thickness and condition of the surfaces is very important. Quite obviously thin spots will receive insufficient pressure in the bonding operation to provide proper flow, transfer and penetration of the glue mix. Conversely, thick areas will receive excessive pressure, a condition promoting excessive flow and penetration of the glue mix. No less important is the inability of the spreader operator to maintain a uniform glue spread if the stock presented to him is not reasonably uniform in thickness. Control over the thickness of veneers must be brought about prior to the bonding operation as it is too late to do much about thick and thin stock once it is presented to the spreader crew.

It was mentioned earlier that wetting of the wood substance by the glue mix is important to the creation of a good bond. This statement is based on the theory that under some conditions much of the strength and permanence of a glue bond is the result of a strongly polar attraction between the glue and the wood itself. This theory is opposed to an earlier held viewpoint that a mechanical interlocking of the glue within the wood voids was entirely responsible for the bond strength and permanence. Therefore, any contamination of the wood surfaces by such nonpolar substances as oil or grease or preparation of the wood surfaces in such a manner that the polarity of the wood will be destroyed may decrease the attraction between the wood and the

glue and result in inferior bond quality. Allowing veneers or lumber to remain on flats or in storage for long periods of time after preparation for gluing can possibly reduce the force of specific adhesion. In fact, it is suspected that many species, including ponderosa pine, should be bonded very quickly after the stock is prepared for gluing, especially when urea resins are used as the bonding agent. Control over this phase of the bonding operation depends on careful scheduling of veneers and wood so that there is no need of its being stored over long periods of time before bonding and careful handling to prevent contamination.

Temperature of the stock before gluing has a definite influence on the fluidity of the glue mix and its curing characteristics—especially in cold press bonding applications. The properties and activity of the spread glue are governed by the actual glue line temperature. They are not directly influenced by the temperature indicated by a thermometer located five or six feet high on a convenient post or, in the case of hot press bonding operations, by the platen temperature.

Thus, stock presented to the glue foreman for assembly into panels should meet certain prescribed standards of uniformity for moisture content, thickness, condition of the surfaces to be bonded and temperature or the other quality control measures adopted will be only partially effective.

Glue Spread

The use of more glue than is acually necessary to obtain a satisfactory bond is not only expensive but can cause a reduction in glue line quality through its effect on the behavior of the glue during bond formation. Conversely, less glue than the optimum quantity always results in decreased bond quality. Attempting to lower production costs by arbitrarily reducing the rate of glue spread is usually very poor economy.

Control over the quantity of glue spread per unit of glue line area should be a relatively simple operation if (1) the glue mixes are of uniform consistency from batch to batch and remain so until consumed, (2) the spreading equipment is maintained in good condition and is properly adjusted and (3) the stock being fed through the spreader is reasonably uniform in thickness and smoothness of surface.

Methods of measuring the rate of glue spread usually involve weighing a piece of veneer both before and after it is passed between the spreader rolls and converting the gain in weight to spread per 1,000 square feet of glue line area. The most satisfactory size sample to use for spread determinations is one that equals or approaches the width of the veneers used in production. A hanging balance calibrated in grams or ounces from which is suspended a wood or metal bar having clips to hold the veneer is ideally suited for this purpose. The use of small sized pieces of veneer for such determinations is inaccurate because pressure from the spreader rolls would be higher on a small test piece than on full width veneers used in production. For maximum uniformity of spread, all veneers should be passed through the spreader with the grain direction at the same angle to the spreader rolls.

It is possible to maintain almost any prescribed rate of glue spread within reasonable limits with little or no necessity for frequent adjustment of the spreader as long as mixes of uniform consistency are prepared, a suitable spreader in good working condition is used, and the condition of the veneers remains relatively constant.

The spreading equipment must not only be suitable for the type of resin being used but it must be kept in good condition if uniform spreads are to be maintained. A rubber rolled spreader with rolls having between 16 and 20 grooves per inch is recommended for use with cold press urea resin mixes. Spreader rolls having between 20 and 24 grooves per inch are more suitable for spreading unextended resins of all types and particularly those of the phenol type which do not require such high rates of spread. Frequent regrooving of the spreader rolls will not be necessary if the rolls are properly cleaned at the end of each working day and narrow veneers are not always passed through the same areas of the rolls. Non-uniform spreads are frequently traced to worn spreader rolls, worn bearings, rolls not in adjustment and doctor rolls not in alignment with the spreader rolls. The corrective measures here are obvious.

Too much variation in the stock in regard to thickness, smoothness, flatness and porosity can also cause non-uniform spreading and for this reason such variations should be reduced as much as possible consistent with the raw materials and manufacturing equipment available. It goes without saying that a change to veneers of different thickness and different sizes will require adjustment of the spreader. It is realized that variation in stock cannot be eliminated but in most instances the amount of such variation can be held within workable limits without excessive cost.

Adjustment of the spread should be made by qualified personnel with the aid of sample veneers and a balance and not by haphazard judgment on the part of anyone in the spreader crew if maximum economy and glue bond quality are to be realized.

Assembly Time

The primary effect of increasing increments of assembly time on bond formation is a reduction in the degree of flow, transfer and penetration of the glue mix. If assembly times are too long, the sequence can be halted at any point by the thickening and hardening of the resin and the resultant bonds will be substandard. However, assembly times so short that excessive flow and penetration occurs will likewise result in substandard bonds—though from vastly different reasons. For each type of glue

and set of bonding conditions there is a range of assembly time limits which will promote the production of uniform bonds of acceptable quality. Broad limits usually can be prescribed by your resin glue supplier but optimum limits for any operation can only be obtained by experimentation. Once these limits are established, however, control measures are obvious. The general relationship between assembly time and bond strength for all resin glues will be similar to the illustration for resorcinol resin glue in Figs. 2 and 3, but specific values of bond strength and assembly time will be different for each glue.

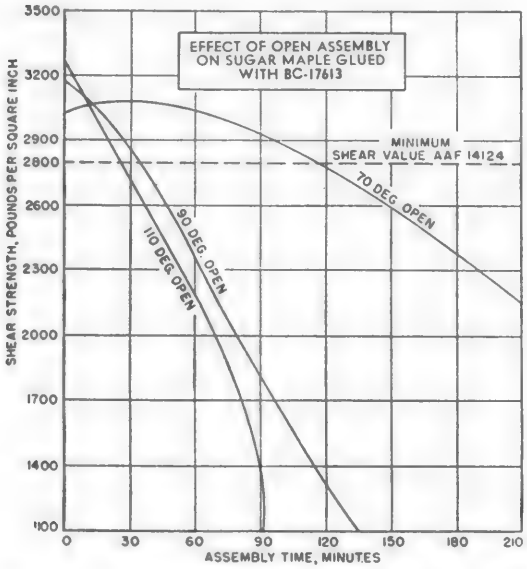

Fig. 2.—Effect of open assembly time on shear strength of sugar maple glued with Bakelite resin glue BC–17613

Bonding Pressure

The function of pressure in bond formation is to bring the mating surfaces to be bonded into contact thus providing the conditions necessary for the proper flow, transfer and penetration of the glue mix. Equally important as the total amount of pressure is its proper distribution and maintenance over the entire glue area.

Too much pressure not only promotes excessive flow and penetration of the glue mix but causes permanent compression of the veneers themselves. Insufficient pressure results in a failure to bring the mating surfaces into proper contact and does not provide the conditions necessary for proper movement of the glue mix.

Generally speaking when pressures are applied by mechanical means high density woods require approximately 200–250 psi. for adequate bonding pressure, medium density woods 150–200 psi. and low density woods 100–150 psi. Classification of woods into high, medium and low density groups is usually based on specific gravity as follows:

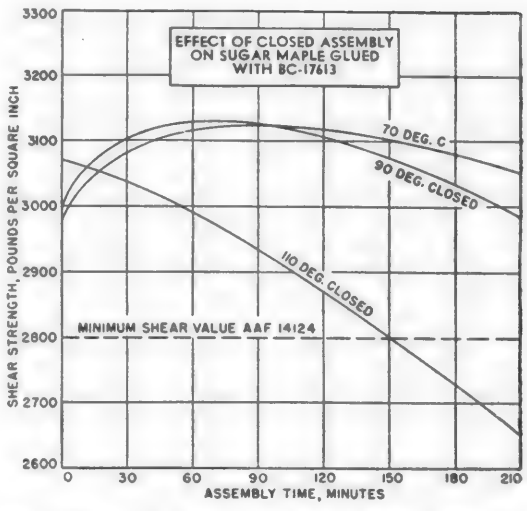

Fig. 3.—Effect of closed assembly time on shear strength of sugar maple glued with Bakelite resin glue BC–17613

	Specific gravity
High density woods	0.56 and over
Medium density woods	0.41–0.55
Low density woods	0.40 and lower

Usually these specific gravity determinations are based on the oven dry weight of the wood and its volume at 12 percent moisture content.

As a further aid in classifying commonly used woods into their proper density classification, the following tabulation is presented.

High density species	*Medium density species*	*Low density species*
Ash, white	Ash, black	Basswood
Beech, American	Cherry, black	Chestnut
Birch, yellow	Elm, American	Cottonwood
Elm, rock	Gum, sweet	Poplar, yellow
Maple, hard	Hackberry	Willow
Oak, commercial red	Magnolia	
Oak, commercial white	Mahogany	
Pecan	Maple, soft	
	Prima Vera	
	Sycamore	
	Tupelo	
	Walnut, American	

Charts or tables indicating the gauge pressures required for a definite glue line pressure for various panel sizes are usually available from press manufacturers but, of course, apply only to a specific press. Such data can be checked or tables prepared by application of the following formula:

$$\text{Glue line pressure (psi.)} = \frac{\text{Gauge pressure (psi.)} \times \text{total area of rams (sq. in.)}}{\text{Panel area (sq. in.)}}$$

Thus the determination of proper glue line pressures and their translation into gauge readings is relatively simple and subject to easy control. On the other hand, much more subtle factors involving the use of labor and equipment can prevent the application of properly distributed pressure to glued assemblies. Presses must be periodically checked for proper alinement of platens and to ascertain that each ram is applying equal pressure. Panels placed in the presses must be perfectly alined vertically and care must be taken to insure that small panels bonded between the same platens or caul boards are of uniform thickness or pressure will not be uniform and damage to the platens can occur. In cold press bonding operations it is also necessary to space the I-beams and clamps in such a manner that an equal area falls under the influence of each I-beam. Their vertical alinement is no less important since it determines how well pressure will be maintained when the bales are removed from the press. Head boards and cauls should be of adequate thickness and uniformity to counteract any inequalities arising from non-uniformity among the veneers.

Usually the glue foreman is responsible for the application of the above mentioned controls but he quite often overlooks one or more factors in the performance of his other duties. Systematic quality control checks are therefore practical and justifiable.

Temperature

Outside of the fact that each resin glue has certain minimum temperature requirements for complete cure, temperature also has a marked effect on the flow and penetration of the glue mix. The rate of cure of thermosetting resin glues increases in direct proportion to increases in temperature at the glue line. Rate and degree of flow and penetration also increase as the glue line temperature rises. Thus, as you might expect, plywood bonds produced under similar conditions in all respects except curing temperature could have vastly different characteristics.

In cold pressing operations flow, transfer and penetration of the resin can occur only if the glue mix itself has the necessary mobility to perform these functions. Similarly, cure of the resin in a reasonable length of time depends solely on the action of the catalyst. Thus, minimum glue line temperatures are specified for thermosetting resin glues because of the effect of heat on all phases of bond formation. In this connection it is once more emphasized that the temperature at the glue line is responsible for the movement and cure of resin glue and that platen temperatures or room temperatures are a factor only in a very remote sense if at all.

When hot rooms or kilns are used to accelerate the cure of bales of cold press panels, adequate circulation should be provided to prevent air stratification. Fans should be located and circulation tested with artificially produced smoke when the room is loaded with bales. When a hot room is not used, the space where the bales are stored should be isolated with baffles four or five feet in height to prevent cold drafts which originate at doors and windows during the winter months from circulating around the bales.

Electrical measuring devices consisting of a thermocouple and a standardized galvanometer possessing a dial reading directly in degrees Fahrenheit are convenient for checking actual glue line temperatures under any and all external conditions. Similarly, recording thermometers are helpful in maintaining a record of the temperature conditions surrounding bales of cold press panels during their curing period.

In hot press bonding operations the recommended platen temperatures for each glue should be maintained uniformly over the entire area of the platens by maintenance of adequate steam pressure (not less than 10 psi. under ordinary conditions), systematic inspection and maintenance of steam traps to insure their proper functioning, and periodic checking of platen temperature with a pyrometer, grease pencils or other means to locate cold spots. In the absence of suitable equipment to check platen temperatures, the platens should be "blown-out" at suitable intervals to eliminate possibly waterlogged areas.

Press closing time should be held to a minimum by proper maintenance of pumps, pump lines and rams.

Pressure Cycles

The length of time a panel must remain under pressure is a function of the type of resin glue used, the glue line temperature, characteristics of the catalyst, amount and characteristics of the extenders, fillers and modifiers used, moisture content of the wood and other factors. Minimum clamp or press time for flat plywood is assumed as having been accomplished when the glue joint has attained sufficient strength to permit removal of the pressure and to allow the section that has been bonded to be stacked or handled lightly without impairing the quality of the glue bond. Certain other types of assemblies such as molded or curved plywood which have stressed glue lines require that the glue bond approach its maximum strength values before release of pressure.

Fig. 4 shows the relationship of the shear strength of sugar maple bonded with BAKELITE BC–17613 resorcinol type resin to clamp time at 70 deg. F., 90 deg. F. and 110 deg. F. Fig. 5 illustrates the relationship between clamp time and wood density. Figs. 6 and 7 indicate how the cure times required for stressed assemblies bonded with BAKELITE BC–17613 vary with temperature.

Specific recommendations regarding minimum pressing cycles for other specific resin glues are available from resin glue suppliers.

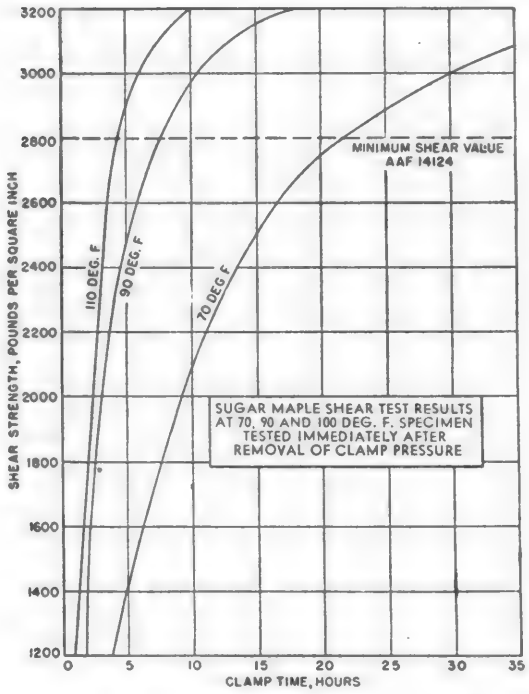
SHEAR STRENGTH, POUNDS PER SQUARE INCH
CLAMP TIME, HOURS
MINIMUM SHEAR VALUE AAF 14124
110 DEG. F
90 DEG. F
70 DEG F
SUGAR MAPLE SHEAR TEST RESULTS AT 70, 90 AND 100 DEG. F. SPECIMEN TESTED IMMEDIATELY AFTER REMOVAL OF CLAMP PRESSURE

Fig. 4.—Shear strength of sugar maple bonded with Bakelite resin glue BC–17613 as affected by clamp time.

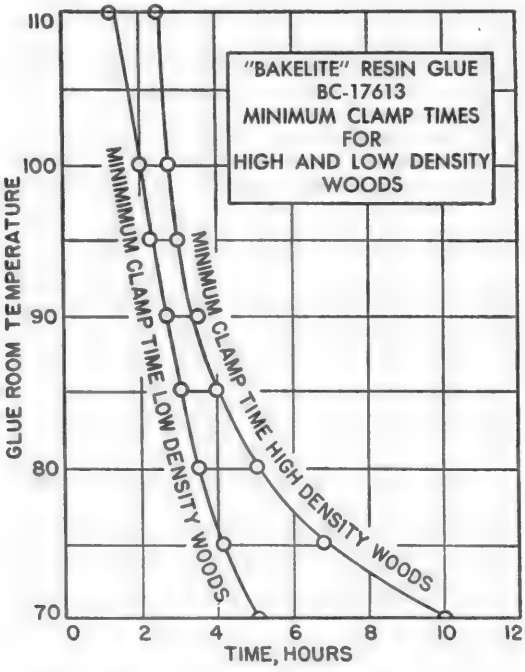
"BAKELITE" RESIN GLUE BC-17613 MINIMUM CLAMP TIMES FOR HIGH AND LOW DENSITY WOODS
MINIMUM CLAMP TIME LOW DENSITY WOODS
MINIMUM CLAMP TIME HIGH DENSITY WOODS
GLUE ROOM TEMPERATURE
TIME, HOURS

Fig. 5.—Minimum clamp time recommendations for low and high density woods bonded with Bakelite resin glue BC–17613.

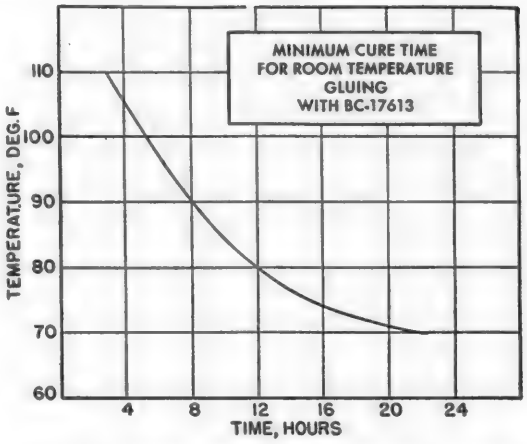

Fig. 6.—Minimum cure time for stressed assemblies bonded with Bakelite resin glue BC–17613 at various room temperatures.

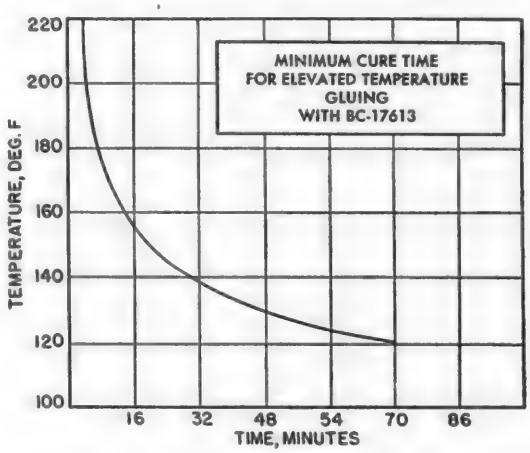

Fig. 7.—Minimum cure time for stressed assemblies bonded with Bakelite resin glue BC–17613 at elevated temperatures.

Product Testing

In the final analysis, the quality of a glue bond can only be measured by subjecting the glued assembly to prescribed test procedures and measuring its strength in terms of the force necessary to destroy it. Such tests not only indicate the quality of the bond but also the effectiveness of the control over the variables inherent in the bonding operation when quality control systems are employed.

In a sense, bond quality can be measured by means of the so-called knife test or examination of the panel trim, available at the trim saws. In fact, for some applications, such tests of bond quality are entirely adequate. However, for a more precise measure of bond strength and bond permanence, there are a number of more or less standardized test

procedures. A very general classification of these tests is given below.

A. Plywood shear tests
   a. tested dry
   b. tested wet
      1. cold soak
      2. immersion in water held at definite temperatures above room temperature up to boiling (212 deg. F.)
      3. cyclic, involving alternate soaking and drying of the test specimens
   c. mold and fungus tests

B. Delamination tests—usually made on 6-inch squares of plywood
   a. dry tests
   b. wet tests
      1. cold soak
      2. cyclic tests involving alternate soaking and drying of the specimens
   c. mold and fungus tests

C. Exposure tests
   a. normal
   b. accelerated

D. Block shear tests and tests on heavy laminated members

All of these tests are described in detail in numerous government specifications, publications of the Forest Products Laboratory, and other formal publications. In the event that the necessary equipment is not available to perform these tests, sample panels may be sent to outside testing laboratories or the Southern Plywood Manufacturers' Association, who regularly conduct bond quality tests on plywood panels submitted by members and nonmembers alike.

While any number of the available test procedures are probably adequate to serve as a check on bond quality in a particular manufacturing plant, there is a very definite need for uniform standards of bond quality to apply throughout the hardwood plywood industry, just as the Douglas Fir Plywood Industry has adopted uniform standards for their industry. Despite the wide variation in the types and grades of hardwood panels produced, it should be possible to construct a suitable set of performance standards which would include all of these types and grades. It is not believed that Commercial Standard CS35–49 Hardwood Plywood—is the answer to the problem in that there is a disproportionate gap between the requirements for Type I and Type II bond quality. Possibly a return to the bond durability standards of Commercial Standard CS35–47 while still retaining the better features of Commercial Standard CS35–49 would provide a suitable basis for such a program. As it stands now, however, there are no uniform standards which have been recognized or adopted by the manufacturers of hardwood plywood as a group and the consumer has little or no basis upon which to judge the performance characteristics or bond quality of the plywood he purchases.

There is very convincing evidence, however, based on the activities of certain groups of hardwood plywood manufacturers, of a genuine desire to improve the situation as it exists today. As an example, the Southern Plywood Manufacturers Association, since its inception less than four years ago, has been spearheading a drive for the adoption of uniform standards for plywood grades and bond quality throughout the hardwood plywood industry. To date their program has also involved the sponsorship of glue clinics, grading schools and the maintenance of a testing laboratory equipped to conduct routine bond quality tests on finished plywood and make resin solids content determinations on resin glues. It is hoped that this and other organizations will eventually be able to foster the general adoption of uniform standards for the entire hardwood plywood industry and enforce the application of these standards as does the Douglas Fir Plywood Association for their industry.

Machining, Handling, Flow of Materials and Control in Gluing

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This paper deals with the problems presented in machining, handling, flow of materials and control in gluing. Some common errors, both in design and in practice, are pointed out, and the importance of correct timing in the sequence of the operations is emphasized. Indiscriminate mixing of species, lack of proper seasoning time, and shortcutting of proper machining operations are all things to be avoided. The value of humidity control is emphasized in the overall picture.

IT IS, of course, obvious that we must have a good adhesive if we are to have a satisfactory glue bond. A prerequisite that is not as well known and certainly not as well observed is proper machining of the wood. The handling of the material after machining is of vital importance, and the timing of the machining with respect to the gluing operation is also important. Because all of the above facts are true, the title of this paper might be rephrased to read, "Satisfactory Gluing Requires Proper Machining, Handling, and Flow of Material, As Well As Process Control in the Glue Department."

A logical point at which to begin the consideration of good preparation for gluing is with the machining. The importance of proper machining cannot be overlooked. If a satisfactory glue bond, or a series of glue bonds is to be accomplished, we must avoid building stresses into the assembly. Unbalanced plywood is such an example, and the reasons for the unhappy results are too well known to require any amplification here.

Importance of Balanced Construction

Most of us have seen steel floor plates or sheets welded together or a repair patch welded into a plate and have noticed the resultant buckling. These are examples of built-in stresses. It is a well-known law that in an object at rest, every action is opposed by an equal and opposite reaction. When unequal stresses are set up the glue line must oppose this stress. If an assembly exerts a constant stress on the glue line, and if this line is subjected to any abnormal conditions, it will in time deteriorate or fail much sooner than a stress-free glue line. The question then arises, how are we to avoid building in these stresses. We can do this in two ways; first, on the drawing board by not calling for unbalanced designs and, second, in our machining and production control. Let us first look at the drawing board side of this picture.

If we are designing a panel with veneer faces we would, of course, have a panel of all-ply construction or with one or more additional inner plies, plus a lumber core. In general usage the term "laminated" is meant to consist of a series of laid-up veneers wherein all of the grain directions are substantially the same. In a "plywood" construction, the grain direction of each pair of plies (moving out from the core) is in the same direction and at right angles to that of the adjacent plies. There are some special stressed-skin applications wherein certain plies are laid at special angles in order to resist calculated strains. This is a special case in which a stress is deliberately locked-in in order to balance out known conditions.

Most people are familiar with the basic advantages of plywood. However, it is idle to design a panel wherein, theoretically half of the wood grain is run in the longitudinal axis and the other half in the transverse axis if we are going to use different species of wood in the paired layers or even the same species but cut in different manners, as for example a vertical-sliced ply with the mating piece rotary-cut.

It is well known that each species of wood has different shrinkage characteristics with changes in moisture content, and to further complicate the picture, these different rates vary both in a tangential and radial direction. It is obvious that if we were to design, for example, a 5-ply panel in which the grain directions were properly balanced, 50–50, the thicknesses well-balanced, but one cross band was maple and the mating cross band was poplar, we would be designing into the panel a stress which would develop whenever the equilibrium moisture was different than at the time of pressing.

Let us turn our attention from the all-plywood panel to the so-called lumber core panel wherein we have a core of solid lumber ¾ inch thick with two cross bands 1/24 poplar and two faces of 1/28 mahogany. In theory it would be desirable to have mahogany on both face and back. Mahogany is more expensive than poplar, and if the panel is one that did not show on two sides, we would use the

cheaper veneer even though we knew it was less than ideal. Many times, however, there will be inferior mahogany; veneer which could not be used for faces, and this can well be worked up into backs.

One other point to consider in passing is the fact that if this panel is to later receive a high-grade finish, it will call for considerable sanding on the face and this must be allowed for in our design.

Essentially, we can recapitulate very briefly on the design side by stating that we should design for balanced conditions, keeping in mind that the term balance includes dimension, grain direction and species.

Achieving Flatness

In producing a lumber core panel, the flatness of the panel will, to a large degree, depend upon the care used in making the core since the large mass of the wood is in the core. If we are going to make a core, say 3 feet wide, and we make this up out of 3 planks each 12 inches wide, the result will be unhappy, even if all 3 planks are dried to the same moisture condition, properly machined and properly glued. The more closely we desire a stress-free panel, the narrower we must cut our pieces of lumber for the core, and then having cut them, we must observe the precaution of reversing every other piece that comes from the same plank. This then might be considered the first precautionary point in our machining and material flow.

By ripping to narrower widths, and in some types of unsupported panel it is customary to rip to widths as narrow as 1½ inch, and then reversing the grain direction either by turning the piece end for end or by turning it over prior to gluing, each individual piece will tend to be balanced by the two adjoining pieces. This practice should be followed, particularly where the panel is so-called face stock rather than core stock. This is so because in the case of face panel there are no restraining veneers.

In its broadest concept, the object of machining is to so prepare the surface that it requires no pressure to hold the machined edges in intimate contact during the gluing operation. This, of course, is easier said than done. When a shop man tells you that he has to use a pressure of 350 to 400 pounds per square inch to glue satisfactorily, he is in effect confessing that his machining is bad or his production flow timing is off, as will be mentioned later, or the designing is unbalanced. However, for the present we will assume the design is proper and this would mean that the machining or production flow timing was off.

Consider the basic machining errors. Lumber as it comes from the dry kiln, even though properly dried, is seldom, if ever, flat in the true sense of the word. If we stock saw this to certain lengths and then send the lumber through chain-feed rip saws and then glue up into panels, we will get a good job with a stress-free panel about as often as we hit a winner at the race track.

When a piece of wood passes through a chain-feed rip saw, it is not flattened down to real flatness. The pressure on the chains of the chain-feed saw should be only sufficient to give traction. Attempting to flatten stock at this machine will tend to wear out all the bearings on the saw without accomplishing the desired results inasmuch as there will still be spring-back in the wood due to resiliency in the pads. The end result is that the two ripping edges of any given piece of lumber can never be guaranteed to be parallel to each other and perpendicular to the faces. This, therefore, means that if we are assembling a core of half a dozen or more of these pieces we would get, if we concede for the moment through happenstance that the edges were parallel to each other, a panel that would look, exaggerated of course, like Fig. 1.

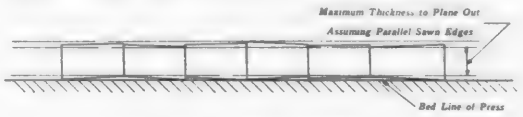

Fig. 1.—End elevation.

Then if we are to hold out to a certain specified thickness, this would mean that we would have to start out with heavier lumber or it would not clean out in the planing operation. What actually happens, however, in attempting to glue up pieces like this is that they tend to buckle in the clamp carrier or bonding machine whether it be high frequency or steam platen type. (See Fig. 2.) In order to overcome that trouble, we design the machine to apply a certain amount of down pressure or the clamp carrier operator goes to work with a mallet. In either case the addition of this down pressure tends to prevent intimate contact rather than attain it. (See Fig. 3.) The operator, therefore, tends to increase the side pressure to restore this contact in spite of the down pressure. The writer has been informed of a press wherein they used as much as 700 pounds per square inch side pressure attempting to glue edge joints, and even at this pressure they were not successful most of the time. In this

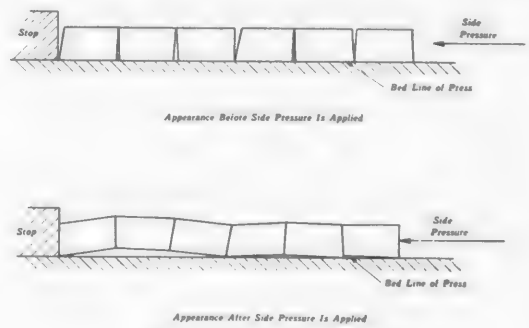

Fig. 2.—Side pressure action.

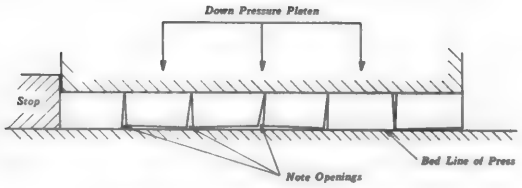

Fig. 3.—Down pressure applied.

particular plant they mistakenly discarded a press rather than correct the evil which was the machining sequence discussed above. Usually about this time the glue salesman is called in and told that his glue is no good.

The only way I know that you can guarantee flat, parallel edges on wood production lines is to face and rough plane the lumber (either before or after stock sawing), rough planing both sides if thickness of wood will permit this. Incidently, this will have an added advantage in that it will often times expose defects which otherwise would not be visible at that point. Now, having parallel flat faces to be in contact with the bed of the chain feed saw, we will, if the saw is in proper operating condition, obtain edges which are perpendicular to the face and parallel to each other. It should be obvious that the reason I propose planing on both sides is that in later gluing up of the cores we will be turning over every other piece, and if these faces were not roughly parallel to each other, we would again be looking for trouble in the glue assembly operation. At this point we emphasize that the saw blade should be in proper condition. Our better manufacturers of chain feed saws have powered them liberally. In other words, they will cut four-quarter stock even though the saw should have been sharpened thousands of cuts before. A cut with a dull saw is the answer to many glue failures. Other speakers have discussed the reasons for this during the course of their papers. I would certainly reiterate that a properly sharpened blade in a properly adjusted chain feed saw is an absolute essential for good gluing operation.

Importance of Timing

The problems of timing in connection with gluing practices are so intimately connected with machining operations that no attempt will be made here to segregate them into separate and distinct headings. Having attained clean, sharp, parallel, straight edges on our lumber, we should now plan to proceed as rapidly as possible to the gluing operation. If these pieces of wood are allowed to lie around, even overnight, we are straying away from best practice. The reason for this should not be hard to see.

Upon fluctuation in relative humidity of the mill and glue room atmosphere, wood stored therein will change in equilibrium moisture content. Since wood does not swell and shrink the same amount in radial as in the tangential direction, straight, parallel gluing surfaces may not be maintained if the wood must pass through areas of uncontrolled relative humidity. This condition is still further aggravated in the case of gummy wood wherein the oils will have a chance to exude.

Other papers have discussed the important factor of "wetting". I will not, therefore, elaborate on this now beyond reiterating the fact that a better wetting action is obtained on fresh cuts than on old ones. Thus we see there are varied reasons for our plant layout, our routing on job cards and our material flow systems to the end that gluing is done as soon after machining as possible.

Much other material has been written on the relative merits of cutter-type surfaces as opposed to sawn-type surfaces insofar as their effect on good gluing is concerned, and I have no wish to enter that controversy at the moment beyond stating that in both cases the sooner we glue the better.

Still talking in terms of panels, both face type and core type, we must now concern ourselves with another very important element of time. That is the time required for the dissipation of moisture which has been added in the glue line, or which has been displaced in position by addition of heat used in curing the glue or by exothermic action of some glues. I am thinking now in terms of synthetic, resin-type glues, particularly, although the remarks will hold generally true with any glue. In the case where water is actually used as a vehicle for the glue, or even where it is part vehicle and part of the reaction, a certain amount of free water will cause a swelling of the wood adjacent to the glue line. If we now attempt to plane this panel before this water has had a chance to equalize or pass to the surrounding atmosphere, we will have sunken joints. This condition is certainly well known. The only reason it arises at all is that some Production Control Department fails in its scheduling or that the mill room foreman slips up and cheats on time. Another fine point to consider is that many glues do not obtain their full strength immediately and, tished as to permit this curing time to elapse. In therefore, our production control must be so estabone plant that used both high-frequency electronic edge bonding and clamp carrier bonding, a local humidity control dry room was located in that department and it was an inviolable rule that all panels had to go into this room for a period of not less than 24 hours. It was one of the functions of the Quality Control Department, of course, to enforce the rule. This was done on the assumption that although the high-frequency bonding would not require this seasoning period, the clamp bonding would, and the inevitable result would be that on occasion the high-frequency-cured panel would go into the conditioning room while the clamp carrier panels went on to a planer. Some types of panels should be submitted to a 30-day seasoning cycle. An example is that for a piano action. These parts are

made from a panel which is ripped into small components which in turn must maintain their shape.

So far we have been discussing machine and glue problems, particularly with respect to panels. Let us now turn our attention to solid parts or sub-assembly components. Take a common case, for example, a mortise and tenon. It is possible to use form cutters on a moulder, and set our tenon heads, preferably on a double end tenoner, and have the set-up man see that it matches the mortise perfectly, yet when it reaches the glue room find that it won't go in at all or that the fit will be sloppy. Here the usual result is that the glue room foreman will pick up the phone and tell the mill room supervisor to get a new rule. Actually what has happened is that the delay between machining and gluing has given the woods an opportunity to come and go as they follow equilibrium moisture content of their surroundings. Where the two mating pieces were stored in the interim, the usual result is trouble.

It is a well-known fact that a round hole drilled in a piece of wood does not stay round, as the wood swells or shrinks. One more place where time is of the essence is the drilling of holes for gluing. It is admitted that often a close cycle is not always feasible; I have in mind a particular component wherein a sugar-pine plate was made up approximately 21 inches long and 45 inches wide, and in which all proper procedures were religiously followed. After gluing it was allowed to air dry 30 days, after which it was finish planed and a piece about 6 inches long and 45 inches wide was cut off. This cut-off piece was then sent through the moulders which beveled and tenoned one face. The main part of the plate was then sent over a cutter to make a mortise so that this so-called tail piece could be reglued at an angle. Before this could be done some nineteen complex operations had to be performed on the front part requiring some 12 working days delay. Great care had to be used to see that these two component parts always remained in the same area to avoid defects when they were glued together.

Importance of Careful Handling

We must not overlook one very important facet of production and that is material handling. Proper material handling is important to avoid damage not only to the future glue line surfaces but to all parts of the components. It is an expensive item in all plants. There are certain material handling precautions that must be observed insofar as good gluing results are concerned. In the first place, care must be taken to see that no damage occurs on the faces which are later to receive the glue. In the second place, the parts must not be piled on trucks in such a way as to cause warping conditions. Panels, for example, should not be piled on a truck so that there are wide overhanging areas. Curved panels must be carefully piled so that the weight of the panels above does not tend to flatten out the curve. This is of particular importance where the later machine operations have to be done on the edges of these curved sections. Material handlers should not be allowed to leave loads in drafty areas or by open windows. These are elementary precautions, but they are frequently violated.

This touches on another point in the production control order for line-up and that is that panels coming out of hot plate presses or high-frequency presses must be allowed to equalize properly and reach room temperature before proceeding to subsequent operations if we are to avoid the danger of building in stresses, for it is a fact that we can build in a stress during the course of the operation as well as in the beginning.

In dealing with curved surfaces, everything that has been said about flat panels applies and even to a greater extent in some cases. It may be desirable at times to pre-form before gluing or even before initial machining in some isolated cases. In autoclave gluing it is generally necessary to make allowances for the condition, rather loosely termed spring back. In dielectric heating presses, generally no precaution need be required for this particular condition, the reason being that the heat is generated rather uniformly throughout the package. In the autoclave type of heating we have a condition of progressive glue line curing, and the variation of actual condition in the wood cells during curing gives a tendency for the curve to spring back or spring forward depending on whether the design is a male or a female die. In either case, for optimum results, stick pile the heated panels after they come out of the press. In the case of flat panels coming out of a hot press we have the choice of stick piling or pack piling. However, with curved surfaces they are of such a nature that pack piling is not possible because of changes in radii.

Other speakers have or will during the course of this panel cover process control in the glue department itself, and for that reason this paper will not discuss that aspect of the problem at all beyond making the suggestion that you tread carefully before you willfully violate any recommendations made by the manufacturer of the particular resin you are using. Resin adhesives are like fine machinery in the sense that they deserve and require care in their use.

It is desirable, in this connection, to keep the parts as dust free as possible, because experience has shown that although so-called wood flour is often used as a glue extender, layers of dust on the glue line itself are frequently harmful in nature.

The Humidity Control Question

And now I touch on a subject not always pleasant because it will cost money, but which, in the writer's opinion, will continue to pay dividends ever afterwards, and that is the subject of humidity control or so-called air conditioning. Overall air conditioning is expensive, so much so that I would find it difficult to justify recommending it. The expensive

feature in normal air conditioning is the de-humidifying. Fortunately, for our industry it is a fact that in most parts of the United States during the greater part of the year, the humidity and therefore the equilibrium moisture content, is below rather than above the norm for interior wood working. To put this in other words would be to state that at least in the northern parts of the country seven to eight months of the year we should be adding humidity to the air in our working areas. This is an inexpensive procedure, and I do stress it. As a matter of fact, the Army Air Forces did require installation of such equipment by all sub-contractors supplying components for its service during World War II.

There are a number of sources of supply for this equipment, but the broad basic principal is the same, namely, the controlled addition of the moisture into the air. One type of system, for example, mixed roughly one part of steam to six parts cold water, using the steam itself as a propellent, and ejected the mixture through a series of fine nozzles in the form of a mist.

In planning such a system, it is very important that you do not overlook the number of cubic feet of air per minute being exhausted from the area by your dust collecting systems. A single 100-inch fan, for example, might easily exhaust 25,000 cubic feet of air per minute. In the case of a humidity controlled area, this air, of course, would be replaced by unconditioned air and, therefore, your humidity system must be able to take care of this requirement in addition to the air at rest.

Recapitulation

We can recapitulate the foregoing thoughts briefly in the following: (1) Avoid designing structures that will cause trouble due to inherent stresses in the structure itself. (2) Don't mix species of wood indiscriminately. (3) Do all of the machining that is required in order to prepare a satisfactory glue surface. (4) Handle the parts carefully. (5) Plan the operation with respect to time in such a manner that a minimum of time elapses between machining for gluing and the gluing itself. (6) Allow proper time for the gluing operation. (7) Allow proper seasoning or conditioning time after the glue assembly before the next machining operation. (8) Avoid storing the parts or allowing them to stand around in drafty places or subject to sudden temperature fluctuations. (9) If at all feasible, have humidity equipment available in all operations prior to gluing and at least the next several operations after gluing. (10) Avoid dusty conditions in glue areas.

Discussion

Mr. X: You mention several different pressures for gluing. What, in your opinion, is the correct pressure to use?

Mr. Stanley: I do not believe there is any exact specific pressure that is best for gluing. Most authorities agree that the best pressure is just enough to bring the parts into intimate contact. The poorer the machining or design, the more the pressure required. Too much pressure is as bad as too little pressure. If you must have a range of pressure for resin adhesives, I would give you a range of 75 to 200 pounds per square inch depending on the species and make-up of the assembly. I would again emphasize that this is only a generalized answer.

Mr. X: You stressed the importance of parallel edges perpendicular to faces. Would this apply to both hardwoods and softwoods?

Mr. Stanley: Yes, this would apply to both hardwoods and softwoods. Because of the spring-back which occurs in hardwoods when passed through the sticker, for example, I would say that the condition is even more important in hardwoods than in softwoods.

Mr. X: You touched on conditions of machines. Would you amplify this?

Mr. Stanley: No machining job is any better than the condition of the machine that produced it. If we are to produce 500 pieces all to fit a certain mating part, it is obvious that all 500 must be alike dimensionally. If there is play, for example in a machine shaft, it is apparent that this condition will not be met. Broadly speaking, I believe poor condition of machines has much to do with various gluing problems—the faults of which are erroneously placed elsewhere.

Mr. X: You stated that with dielectric heating of curved shapes you did not have to allow for spring-back, but in autoclave heating you would. Why?

Mr. Stanley: The apparent reason for this seeming paradox is the fact that in autoclave heating the heat is applied from one side only and has to slowly penetrate layer by layer through the complete assembly. Thus the outer plies are cured and set while the inner plies are still fluid. When the cycle is over and the curved shape is removed from the die, nature and its equalizing process takes over.

Mr. X: You mentioned resin glue in one point in your paper. Are we to assume your paper is predicated on resin glue only?

Mr. Stanley: No, I did not mean to imply that this paper is predicated on the use of resin glue only. The general precautions outlined would apply to almost any adhesive. However, it is well to add that resin adhesives apparently are coming more and more to the forefront, and there is one further very important point; with most glues other than resin you can get a poor bond, a fair bond or a good bond, according to the amount of precaution and care used in the manufacturing process. In the case of resin glue for all practical purposes, you get either a good bond or no bond.

Research in Electronic Wood Gluing

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Many of the physical factors affecting electronic wood gluing have been evaluated in recent years. However, the electrical behavior of the wood, the glue and the wood-glue combination has not been adequately established. The important basic electrical relationships are discussed, and the results of exploratory studies of these characteristics are given.

Introduction

A GREAT deal has been written in recent years concerning electronic or radio frequency wood gluing. The basic theory underlying electronic heating has been developed from the early observation by Siemens in 1864 (when he noted the heating of a Leyden jar being electrically charged and discharged) to the rather complex relationships encountered in current literature on the dielectric behavior of materials. Similarly, the practical aspects of electronic gluing including such factors as generator and electrode design, types of presses, and proper conditioning and machining of the stock prior to gluing have been examined in considerable detail. However, there are many problems still unsolved, especially those concerned with the electrical behavior of the wood, glue and wood-glue combinations during the curing process.

A general study of the theoretical and practical relationships involved in electronic wood gluing has been undertaken at the College of Forestry of the State University of New York. Projects along somewhat similar lines are also in progress at the Canadian Forest Products Laboratory and the British Forest Products Research Laboratory. Investigations of specific electronic gluing problems have been made by the U. S. Forest Products Laboratory and by other governmental and private agencies. References will be made to the data obtained from several of these sources in the following discussion of the dielectrical behavior of wood, glue and wood-glue combinations.

The Wood

Wood in its dry state is a relatively poor conductor of electricity, and as such exhibits the electrical properties usually attributed to an insulating or dielectric material. The electrical factors affecting the dielectric losses or heating of all insulating materials, including wood, are:

1. The *dielectric constant* (e') which is a measure of the polarization which occurs in an insulating material when it is placed in an electric field.

2. The *power factor* (P.f.) which is a measure of the power dissipated in watts in a dielectric material compared to the total power available in voltamperes. Since in alternating current circuits the voltage and current are rarely in phase, i.e., attain maximum or minimum amplitudes at the same time, the power factor may be taken as the cosine of the phase angle (θ) occurring between the voltage and current and is usually written *cos* θ.

3. The *loss factor* (e'') which is a measure of the energy dissipated as heat in a dielectric material, and is equal to the product of the dielectric constant (e') multiplied by the power factor ($\cos \theta$).

4. The *resistivity* (r) or its reciprocal *conductivity* (c) which are measures of the ability of a material to conduct electric current. Both resistivity and conductivity are generally evaluated in terms of a cube of a dielectric material measuring one centimeter in length, width and thickness. In order to facilitate computations, however, some of the results of this study will be given in terms of an inch cube so that the unit for resistivity will then be ohm-inches and that for conductivity mhos per inch.

These electrical properties have been evaluated for some of the commercial species of wood by von Hippel and Dietz (*6*), Miller and Peterson (*2*), and C. Skaar (*3*) of the New York State College of Forestry. The variations in the dielectric constant with wood density and moisture content, and the effects of frequency and moisture content on the power factor of wood observed by Skaar are given in Figures 1, 2, and 3.

Both the wood and the glue may be represented by either equivalent parallel or series electrical circuits, and these are given in their simplest forms in Figure 4. Since our study to date has been concerned with only parallel or selective gluing applications, the concepts of resistivity and conductivity dealt with in this paper are in terms of their equivalent parallel values.

The capacitance of a wood load (C_w in Figure 4) neglecting edge-effects is

$$C_w = 0.224 \times 10^{-12} \frac{A \cdot e'}{d} \text{ farads} \quad \text{--------1}$$

where A is the area of the wood in square inches, e' is the dielectric constant of the wood, and d is the thickness of the wood in inches.

The equivalent parallel wood resistance R_w may be approximated by employing conventional electrical engineering theory (*5*) as

$$R_w = \frac{Xcw}{P.f.} \text{ ohms} \quad \text{----------2}$$

where X_{c_w} is the capacitive reactance in ohms of the wood and P.f. is its power factor.

The capacitive reactance X_{c_w} of the wood is, in turn, by definition

$$X_{c_w} = \frac{1}{2\pi f C_w} \text{ ohms} \quad \text{----------3}$$

where f is the frequency in cycles per second and C_w is the capacity in farads.

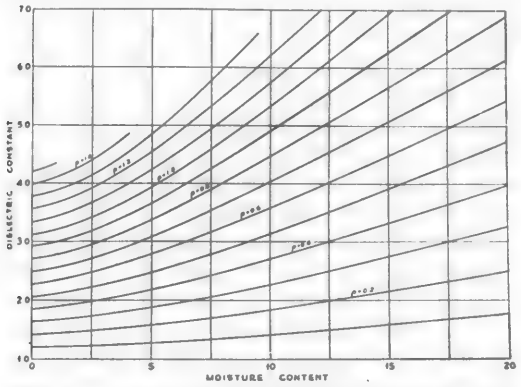


Fig. 1.—Variations in the dielectric constant with moisture content at 2 megacycles for various wood densities observed by Skaar (*3*).

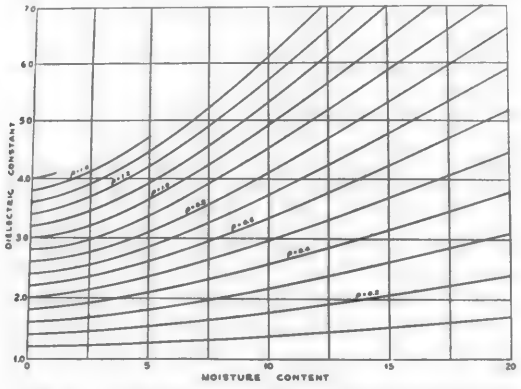


Fig. 2.—Variations in the dielectric constant with moisture content at 15 megacycles for various wood densities observed by Skaar (*3*).

The equivalent parallel resistivity of the wood may be used to calculate its equivalent resistance as follows:

$$R_w = r \cdot \frac{d}{A} \text{ohms} \quad \text{----------4}$$

where R_w is the parallel resistance in ohms when r is the equivalent parallel resistivity in ohm-inches of the wood, d is the thickness of the wood (length of path for the electric current) in inches and A is the area of the wood in square inches.

The heat generated within the wood when it is placed in an electric field is from Ohm's Law

$$P_w = \frac{E^2}{R_w} \text{watts} \quad \text{----------5}$$

where P_w is the heat generated or power dissipated in the wood in watts when E is the effective voltage of the electric field and R_w is the equivalent parallel resistance of the wood in ohms.

By suitable substitutions Equation 5 can be transformed to read

$$P_w = 1.41\ E^2 f e'' \text{ watts per cubic inch} \quad \text{-----6}$$

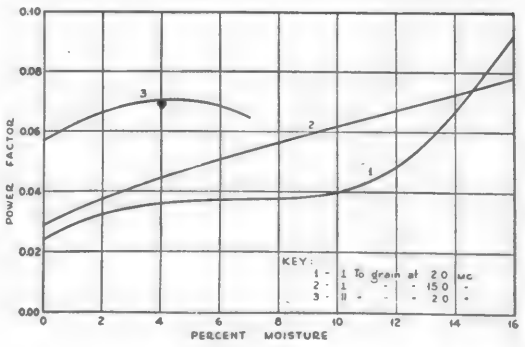
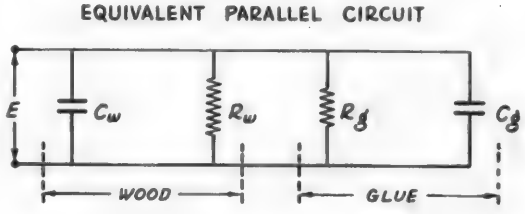


Fig. 3.—Variations in the average power factor of wood with moisture content observed by Skaar (*3*).



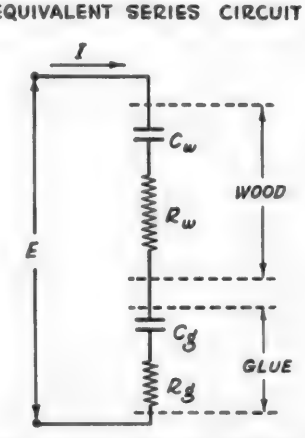


Fig. 4.—The equivalent electrical circuits of a wood-glue load (A) in parallel, and (B) in series, where:

E = R.F. voltage across the wood-glue load.
I = R.F. current through the wood-glue load.
C_w = Capacitance of the wood.
R_w = Resistance of the wood.
R_g = Resistance of the glue.
C_g = Capacitance of the glue.

where P_w is the heat is watts per cubic inch of wood when E is the voltage gradient in kilovolts per inch, f is the frequency in megacycles and e″ is the loss factor of the wood.

Since the apparent electrical resistance encountered in dielectric materials provides a simple means of calculating the power dissipation which may

occur, one phase of our study has been devoted to an examination of the equivalent parallel resistances of the wood and the glue. Using a Boonton Q-Meter[1], type 160-A and a small edge-gluing press, Fig. 5, measurements were made on basswood, *Tilia americana,* L. The parallel resistance of 4″ x 4″ x 1″ panels was obtained at 5, 10 and 15 percent moisture content, at 5, 10 and 15 megacycles, and at 50 psi and 150 psi edge pressure. Following the Q-Meter instructions, the electrodes of the press were made part of the Q-Meter circuit so that any extraneous capacitive, inductive or resistive effects due to leads and press components were eliminated from the calculations. The average of ten measurements obtained under each of the several measuring conditions were used in plotting the curves shown in Fig. 6. These were also used in the statistical determination of the regression equations relating the various variables. The following equations indicate as a first approximation the dependence of the resistivity of basswood on moisture content in the range 5 to 15 percent.

At a radio frequency of 5 megacycles:

$$\text{Log } r = 6.50968 - 0.04659\ MC \quad \text{---------7}$$

At a radio frequency of 10 megacycles:

$$\text{Log } r = 7.03872 - 1.31180 \log MC \quad \text{-----8}$$

At a radio frequency of 15 megacycles:

$$\text{Log } r = 6.47292 - 1.01452 \log MC \quad \text{-----9}$$

where log r is the common logarithm of the resistivity, r is the resistivity of wood in ohm-inches and MC is the moisture content in percent.

Equation 7 reveals that at a radio frequency of 5 megacycles the logarithm of resistivity is an inverse linear function of the moisture content. Stamm (*4*) and others have found a similar relationship to exist when the resistance of wood is measured with direct current. Equations 8 and 9 indicate that at the higher radio frequencies, the logarithm of the resistivity varies inversely as a linear function of the logarithm of moisture content. Similar variations of conductivity versus moisture content were encountered by von Hippel and Dietz (*6*) for measurements made at very high radio frequencies (70 to 90 megacycles). It may be pertinent to note that Walker (*7*) established three expressions for the conductivity of cotton cellulose as a function of moisture content: 1. Below 3 to 6 percent, the logarithm of conductivity varied linearly with the percent moisture content. 2. Between 6 and 10 percent, the logarithm of conductivity varied linearly with the logarithm of moisture content. 3. From 10 to 23 percent, the logarithm of conductivity varied linearly with the relative humidity.

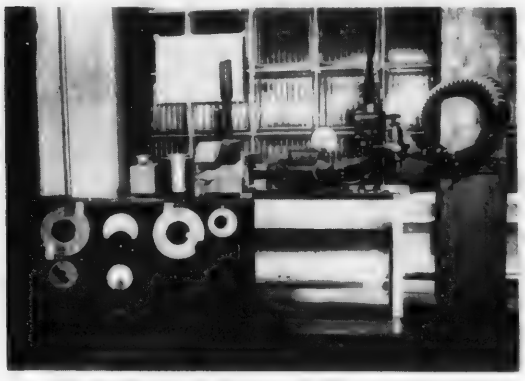


Fig. 5.—The Boonton Q-Meter, type 160-A and the small edge-gluing press.

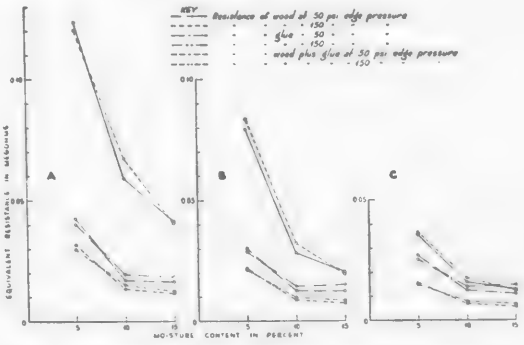

KEY
Resistance of wood at 50 psi edge pressure
" " " 150 " " "
glue 50 " " "
" 150 " " "
wood plus glue at 50 psi edge pressure
" " " 150 " " "
A
B
C
EQUIVALENT RESISTANCE IN MEGOHMS
MOISTURE CONTENT IN PERCENT

Fig. 6.—Variations in the equivalent parallel resistance of the 4″ x 4″ x 1″ basswood panels with moisture content.

A. At a radio frequency of 5 megacycles.
B. At a radio frequency of 10 megacycles.
C. At a radio frequency of 15 megacycles.

Another factor which has been examined is the effect of electronic heating on the strength of the wood during an edge-gluing operation. The toughness test developed by the U. S. Forest Products Laboratory was employed as the criterion for loss in wood strength. Samples measuring 10″ x 5/8″ x 5/8″ of basswood, red oak, hard maple, yellow poplar and mahogany were subjected at a radio frequency of 5 megacycles to voltages up to a gradient of 8000 peak volts per inch for periods up to 3 minutes duration. These restrictions on voltage and heating time exceed the usual maximum conditions imposed during edge-gluing. The wood samples were matched in pairs for specific gravity, and only samples free from defects and having a slope in grain of 1 in 20 or less were tested. One piece from each pair was subjected to the r.f. voltage, and all samples were conditioned to approximately 6 to 7 percent moisture content prior to testing even though this is not a prerequisite in toughness tests.

The data from this limited study were analyzed by means of a "t" test of paired samples. The results indicate that there is no significant loss in strength in wood under the conditions given in Table 1. The tendency for mahogany to overheat and burn is shown by the fact that it reached a crit-

[1] The quantity Q is known as the quality factor or "figure of merit" of a resonant electrical circuit. By definition, the Q of a circuit containing resistance and capacitance in parallel is $Q = R_p/X_{cp}$ where R_p is the equivalent parallel resistance in ohms and X_{cp} is the parallel reactance in ohms of the capacitance C_p.

TABLE 1.—THE EFFECTS OF A HIGH VOLTAGE RADIO FREQUENCY FIELD ON THE TOUGHNESS OF SEVERAL SPECIES OF WOOD

Species of wood tested	Number of pairs of samples	Control Samples				Peak R. F. voltage v/in.	Heat cycle in min.	Final temp. range in °F.	Test Samples			Statistical analysis of paired samples	
		Aver. % M. C. at test	Aver. Sp. Gr. at test	Sp. Gr. range at test	Aver. toughness in-lbs.	S. D. of toughness			Aver. % M. C. at test	Aver. Sp. Gr. at test	Sp. Gr. range at test	"t" value	Level of significance
Basswood	26	6.6	0.46	0.41 —0.51	110.8	13.9	8000	3	265 —300	5.9	0.46	0.41 —0.51	113.6	14.3	1.07	None
Yellow poplar	25	7.1	0.45	0.43 —0.47	104.6	8.0	8000	3	240 —270	6.7	0.45	0.43 —0.47	104.4	6.8	0.09	None
Hard maple	30	6.2	0.71	0.67 —0.76	243.2	53.8	8000	3	270 —315	6.1	0.71	0.67 —0.76	249.2	46.9	0.55	None
Mahogany	15	7.0	0.38	0.37 —0.40	53.3	15.4	8000	1	215 —300	7.0	0.38	0.37 —0.39	49.8	13.2	0.38	None
Red oak	30	7.0	0.66	0.63 —0.69	161.0	22.3	8000	3	285 —315	6.6	0.66	0.62 —0.69	168.8	20.3	1.67	None
Basswood[1]	19	7.0	0.47	0.43 —0.50	107.6	13.1	8000	3	235 —260	6.8	0.47	0.44 —0.51	106.3	9.3	0.49	None
Red oak[1]	9	7.0	0.66	0.63 —0.69	226.4	47.4	6400	3	240 —300	6.9	0.65	0.63 —0.69	256.3	56.7	2.38	5%
Mahogany[1]	19	7.0	0.38	0.35 —0.41	42.2	12.3	8000	1	240 —290	7.0	0.38	0.36 —0.41	43.0	16.6	0.32	None

[1]Samples heated in form of boards 36" x 2" x 3/8", then cut to standard sample size 10" x 3/8" x 3/8".

ical temperature range in only one minute of heating. Similarly, the oak when heated in board form could not withstand more than 6400 peak volts per inch without burning.

The Glue

Since the resin glue used in an electronic gluing process forms the main power consuming load on the r.f. generator, its electrical characteristics are of paramount importance. The results of a study made at the College of Forestry on wet mixes of a number of commercially available resin glues have been given elsewhere (8) and are reproduced, in part, in Table 2 and Figs. 7 and 8.

The glues being used for radio frequency wood-gluing at the present time are mainly the room-temperature and intermediate-temperature setting urea, resorcinol and phenol-resorcinol resin adhesives developed for cold-press gluing. Some hot-press melamine adhesives also have found application in this field. The synthetic resin glues lend themselves to this process quite readily due to the fact that they are of the thermosetting type, and will show a marked reduction in curing or setting time when the glue line temperature is raised to the range 165° F. to 240° F.

A rigorous determination of the electrical resistance of a wet glue line between two pieces of wood would require that the dimensions of the glue line include not only the external glue line but also the internal glue which has penetrated into the wood cavities. The moisture in the liquid glue will also change the electrical characteristics of the wood substance immediately adjacent to the glue line. The dimensions of the internal glue line depend upon the penetration obtained, which in turn is affected by the porosity and moisture content of the wood, the mixed ratio and the amount of glue spread, the pot life or rate of change in viscosity of the glue with time, the assembly time (open and/or closed), the pressure used during the press time and the angle which the grain of the wood makes with the glue line. In addition, a flow period may exist dur-

Fig. 7.—Variations in the r.f. conductivity due to percent hardener measured at 4 megacycles.

TABLE 2.—THE R.F. CONDUCTIVITY IN MICROMHOS PER CENTIMETER AND THE DIELECTRIC CONSTANT OF COMMERCIAL RESIN GLUES AT 4, 8, 12 and 16 MEGACYCLES

Sample	Basic type of resin	Mix ratio[1]		Dielectric constant				R.F. Conductivity[2]			
		Hardener	Water	4 mc	8 mc	12 mc	16 mc	4 mc	8 mc	12 mc	16 mc
B	liquid urea	—	—	69.2	65.3	63.8	63.8	202	231	263	313
	" "	20	—	——	——	——	——	3410	3460	3520	3580
C	" "	—	—	52.2	48.8	48.0	47.8	37	60	75	98
	" "	15	—	35.5	32.1	28.8	21.4	1174	1246	1310	1400
D	" "	—	—	50.2	47.0	45.6	45.0	40	61	83	107
	" "	13	—	48.4	42.3	35.6	34.2	725	751	784	824
F	powdered urea	—	60	——	——	——	——	2054	2114	2250	2347
H	liquid resorcinol	—	—	——	——	——	——	4150	4190	4280	4240
	" "	17	—	——	——	——	——	2570	2630	2760	2760
J	powdered melamine	10	40	36.9	35.1	31.9	31.4	978	1015	1080	1176
Tap water		—	—	82.3	83.8	86.6	89.0	224	231	248	273

[1]The mix ratio was based upon the manufacturer's instructions, and consisted of 100 parts by weight of the basic resin glue plus the parts of hardener and/or water as indicated.

[2]The unit of conductivity is the reciprocal-ohm or mho per unit length. For convenience the unit used in this table is the micrombo or one-millionth of a mho per centimeter.

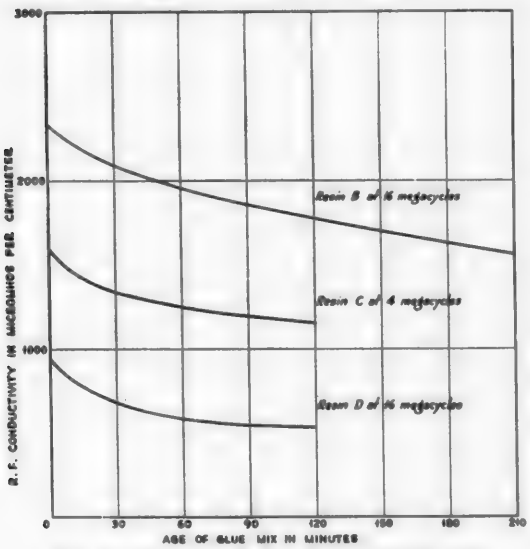


Fig. 8.—Variations in the r.f. conductivity with mixed-age of resin glues.

ing the early stages in an r.f. gluing process when the heated glue may penetrate into the wood to the extent that a "starved joint" results.

Considering all of the variables mentioned above, the chances of obtaining significant dimensions for a glue line *in situ* seem small indeed. As a consequence, the component of the total resistance of a wood-glue combination attributable to the glue line was developed in terms of an equivalent parallel resistance.

A wet glue line between the parallel plates of a load capacitor may be represented by a capacitance C_g and a resistance R_g in parallel, as in Fig. 4-A, or in series, as in 4-B. Due to the relatively high conductivity of most glues and the physical dimensions of the external glue lines, the capacity effect is negligible and the glue can be represented solely by the resistance R_g. The equivalent resistance of the glue may then be calculated by

$$R_g = \frac{R_w \cdot R_{w+g}}{R_w - R_{w+g}} \text{ ohms} \quad \text{----------10}$$

where R_w and R_{w+g} are the resistances of the wood alone and the wood-glue combination, respectively.

The effective parallel resistance of a single glue line in the 4″ x 4″ x 1″ panels, and for one or more glue lines in the larger press panels are given in Fig. 6 and Table 3.

The power dissipated as heat in the glue is obtained by rewriting equation 5 as

$$P_g = \frac{E^2}{R_g} \text{ watts} \quad \text{----------11}$$

Thus, by inspection it becomes evident that if R_g is decreased (i.e., conductivity of a glue is increased) the heat generated in a glue line in an edge-glued panel is increased. If in an edge-glued panel the glue lines are more conductive than the wood (total R_g is less than R_w), the power dissipated as heat in the glue will be greater than that dissipated in the wood in the ratio

$$\frac{P_g}{P_w} = \frac{R_w}{R_g} \quad \text{----------12}$$

This relationship indicates the power dispersal which will occur during an edge gluing operation, and is the reason for making a glue as conductive as possible short of the arcing or the excessive drying point in order to increase the selectivity of the glue line heating.

It is interesting to note that in a *perpendicular heating* operation (i.e., curing of flat and molded plywood or laminates by r.f. heating) the equivalent resistance of the wood and the glue may be considered to be in a series circuit so that the power equation becomes $P = I^2R_T$ watts where I is the total effective current through the wood-glue load in amperes, and R_T is the total series resistance in ohms ($R_T = R_w + R_g$). In this case an increase in the selective heating of the glue lines would require that the glue be made less conductive in order to have R_g as large as possible. Due to the physical dimensions of a glue line in any practical perpendicular heating process, R_g will consistently be less than R_w, and the main electrical heating will take place in the wood. The glue lines, in turn, will be heated by thermal conduction from the wood layers.

Another factor to be considered is the power density. Since the volume of the glue lines is much less than the volume of the wood, the power dissipated as heat in the glue lines will be many times

greater than that generated in the wood. Consequently, even though the effective resistance of the glue lines may be of the same order of magnitude as that of the wood, there will be a tendency for the "heating effect" to be concentrated in the glue lines.

Lacey and Howe (*1*) in their study of the electronic edge-gluing of English beech with a group of British resin adhesives developed the relationships between voltage gradient and heating time shown in Fig. 9. They found that the arcing line for their urea glues was well above 6000 volts per inch and that the damage line appeared to be non-existent. On the other hand, for some resorcinols, the arcing line dropped to the V'_A position, and for caseins the arcing line was below the operating line (V_o) precluding the use of caseins in electronic gluing.

At the College of Forestry, we are currently engaged in an attempt to correlate voltage gradient and heating time with glue conductivity in an effort to determine an optimum range of conductivity for edge-gluing operations.

The Wood-Glue Combination

In the final analysis, it is the electrical behavior of the wood-glue combination which we must understand in order to perfect our methods and increase efficiency in the electronic gluing operation. As shown in Fig. 4-A, the simplified circuit for electronic edge-gluing relates the resistances and capacitances of the wood and the glue in a parallel arrangement. The effective resistance of the wood-glue load employing standard electrical engineering theory is

$$R_{w+g} = \frac{R_w \cdot R_g}{R_w + R_g} \text{ ohms} \quad \text{----------13}$$

The total radio frequency power dissipated as heat in an edge-glued assembly during the initial stages of a gluing cycle is

$$P_T = P_w + P_g = \frac{E^2}{R_{w+g}} \text{ watts} \quad \text{----------14}$$

or by substitution

$$P_T = \frac{E^2(R_w + R_g)}{R_w \cdot R_g} \text{ watts} \quad \text{----------15}$$

It may be well to emphasize at this time that Equations 14 and 15 indicate the required input power to an edge-glued assembly when the glue is wet. As previously noted, the resistance R_g of the glue will change as the curing cycle progresses so that eventually the electrical properties of the glue approach those of the wood. The wood and the glue no longer form parallel paths for the r.f. current and the input power is reduced to approximately the level given by Equation 5.

Again employing the Q-Meter, but with an industrial sized edge-gluing press, the electrical properties of basswood panels measuring 36" x 25" x 1" were obtained at 5 megacycles and 5 percent moisture content. The equivalent parallel resistance, the Q and the power factor of the load were evaluated for a varying number of glue lines. The results of this investigation, given in Table 3, and the data of Fig. 6 indicate that the number of glue lines, the moisture content of the wood and the radio frequency of operation definitely affect the electrical resistance of the wood-glue combination. In contrast to these factors, the edge pressure does not exercise a great effect on the observed values.

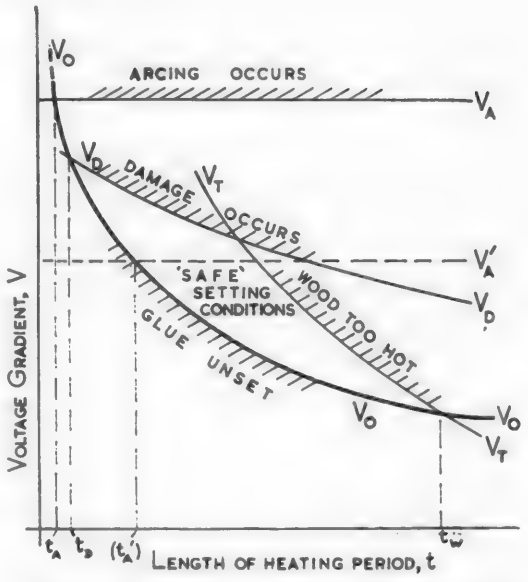


Fig. 9.—An analysis of voltage gradient and heating time factors in electronic edge gluing proposed by Lacey and Howe (*1*) where

V_o = Voltage gradient required for proper curing of a resin glue.
V_T = Voltage gradient above which the wood is heated excessively.
V_D = Voltage gradient above which the glue line suffers immediate or long-time degradation.
V_A = Voltage gradient above which the glue arcs.
V'_A = Voltage gradient above which certain glues arc.
t_A = Heating time at which arcing occurs with voltage V_A.
t_D = Heating time at which damage occurs with voltage V_D.
t'_A = Heating time at which certain glues arc.
t_w = Heating time above which the wood heats excessively.

TABLE 3.—THE PARALLEL RESISTANCE, Q AND POWER FACTOR OF A WOOD-GLUE COMBINATION FOR A VARYING NUMBER OF GLUE LINES

Number of glue lines	R_{load} in ohms	R_{glue} in ohms	Q_{load}	$P.f._{load}$
0	2036	——	28.7	0.035
1	1286	3356	23.1	0.043
3	754	1198	13.9	0.072
5	511	682	9.3	0.108

Referring once again to the diagram of Lacey and Howe (Fig. 9), the region of operation during an electronic edge-gluing process is bounded by the V_o line below which the glue is uncured, by the V_T line above which an excessive heat loss occurs in the

wood, and by the V_D line above which such damage as too rapid drying of the glue or long-time deterioration of the glue lines may result.

Needless to say, these boundaries may be extremely sensitive to such factors as:

1. Wood species.
2. Type of glue.
3. Mixing ratio.
4. Mix-age or viscosity of the glue mix.
5. Glue spread.
6. Assembly time.
7. Stock preparation.
8. Press operation.
9. Factory temperature-humidity conditions.

However, under any given set of these conditions, the area of "safe-setting conditions" can be delineated. It is within this region then that optimum efficiency and satisfactory performance in an electronic gluing process can be attained.

Practical Aspects of Electronic Gluing Research

From a practical viewpoint, we know that wood can be successfully glued by electronic heating. The many mechanical and physical factors which have proven to be critical to the success of this process have been investigated and are now under constant surveillance and control in most factories employing this type of equipment. The results of the past, present and future investigations into the electrical behavior and requirements of the wood, glue and wood-glue combinations should prove to be of equal value.

As applied to present equipment and practices, the results of research in electronic gluing to date indicate that within certain limitations:

1. The data available in the literature on the electrical properties of wood and glues permits the design or application engineer to calculate the electrical characteristics of a wood-glue load.

2. The maximum power output required from an r.f. generator may be approximated for any particular load, thus indicating the size of the r.f. generator required for the job.

3. The concept of a region of "safe-setting conditions" permits an evaluation of the voltage-heating time relationship required for maximum efficiency and satisfactory performance of the equipment.

4. The r.f. voltage is a definite criterion of the power input to the load. In contrast to the rather complex equipment and complicated procedures required to measure the electrical characteristics of a wood-glue load, a simple r.f. peak reading voltmeter provides a direct indication of optimum tuning whenever a load is altered in size or make-up.

5. Modification of present resin glues, not only to provide increased conductivity in some cases, but also to increase the chemical reactivity of the basic polymeric constituents at elevated glue line temperatures is desirable.

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Discussion

E. George Stern (Virginia Polytechnic Institute): I congratulate the author on the manner in which he investigated the subject. I wish that more investigators of wood would give consideration to the elimination of variables by matching for variability and specific gravity or by correcting for specific gravity as was done in this case. I am convinced that the data presented on such a basis are more valuable since they allow a more direct and significant comparison with a smaller number of tests.

Mr. X: Why did you pick the toughness of wood as the basis for examining the effects of the radio frequency heating on wood strength.

John M. Yavorsky (New York State College of Forestry): The choice of the toughness test was somewhat arbitrary since we could have used any one of the several tests of wood strength. However, the toughness test has been shown to provide a very sensitive measure of the degradation in wood strength due to shortening of the cellulosic chains during incipient decay. Similarly, this test should indicate any degrading effects which might possibly occur due to molecular agitation brought about by the high frequency electric field.

Adhesive Developments and Supplies for Defense

N. V. POLETIKA, *Laboratory Manager Timber Engineering Company, Washington, D. C.*

The status of post World War II technical progress in adhesives developments is reviewed and factors influencing current and intensified emergency supplies are outlined.

Introduction

THE development of new adhesives seems to be something of a seasonal affair in the United States. The seasons, however, are not the pleasant changes in the weather but, unfortunately, seem to be characterized by periods of national emergency. In periods of peace the demand for adhesives is primarily for civilian production in which competition forces the adhesive manufacturer to concentrate on improving his manufacturing efficiency and to lower the cost of his adhesives through various modifications in existing formulations and through the development of substitute materials. In defense production, on the other hand, cost is only of secondary consideration and in many instances, maximum durability is the most important requirement. These different objectives coupled with an over-all increased production which attends a mobilization effort are responsible for the acute scarcities and confusion which describe the current adhesive situation.

Adhesive Developments After World War II

There is no need to trace the developments of the different types of adhesives which were in use during World War II since a great deal has already been published on this subject. Post-World War II developments deserve consideration, however, since many companies which were in war work during the last emergency have not had much occasion to keep up with adhesive developments but are now again in a position where this information is of vital interest to them. There is, of course, no clear-cut line of demarcation between the period of the last war and the subsequent peace, and therefore, some of the adhesive developments currently in use were started a good many years ago.

Adhesives for Interior Use

When the forest products industry returned to civilian production in late 1945 and early 1946, it found that the demand for civilian goods was tremendous. In furniture manufacturing the need for animal glue for panel and assembly work was so great that the suppliers of this glue were unable to satisfy the ever-growing demand. To fill in this discrepancy in the supply and demand, the polyvinyl acetate adhesive was offered to the wood-using industry. The polyvinyl acetate adhesive will produce a strong joint after a half hour or less in the clamps. This adhesive has now found a place for itself in the gluing of certain wood products where a great amount of moisture resistance is not required.

Animal glue is currently much the same type of material that has been used for many a decade. It has maintained a very important position in the furniture and other industries which produce glued wood products.

Another interesting development for joints in which moisture resistance is of secondary importance, is the introduction of a ready-to-use vegetable adhesive for assembly gluing. It is claimed that after 40 minutes under pressure there is sufficient set to allow handling. This glue is essentially the same vegetable material which has been used for many years by the woodworking industry, except that it has been converted from powder to liquid form.

Adhesives for Moisture Resistant Joints

The post-World War II period saw a tremendous expansion in the use of urea formaldehyde adhesives both for assembly and plywood gluing. While no startling developments in urea formaldehyde resins took place in this period, certain modifications and refinements deserve consideration.

One noteworthy modification in urea formaldehyde adhesives was the use of different hardeners with the same resin, to permit its use for both cold-press and hot-press operation. These formulations are now in common use and greatly simplify the handling and storage problems in a fabricating plant.

Another important modification was the development of liquid urea adhesive mixtures with low-solids content. These formulations are quite adaptable to bulk handling. Many manufacturers of glued wood products now purchase their adhesive by the tank car and distribute the adhesive to various portions of their plant by pumping through a system of pipes. The longer storage life, which is characteristic of the low-solids mixture, makes possible the purchase of large quantities of material with a maximum assurance that spoilage will be insignificant. Companies now using the adhesive in this way are reporting substantial savings in handling costs.

The increase in the use of high-frequency core machines in furniture and other plants has promoted the development of urea adhesives which are spe-

cifically designed for this use. Most glue companies have several formulations which they recommend for high-frequency gluing.

Synthetic resin adhesives, and especially urea formaldehydes, do not perform well when the gluing conditions result in an excessively thick glue line. Fortification of the basic urea resin by addition of other materials has improved the crazing resistance of the glue line, and with the addition of some materials, the water-resistance of the glue has also been substantially increased. As a matter of fact, use of some of these improved ureas may well be possible in certain phases of defense production where fully waterproof adhesives are now specified, since some of the fortified ureas exhibit satisfactory joint strengths after exposure to boiling water.

There are many gluing operations where rapid curing of a moderately water-resistant glue line is necessary, but only simple clamping and curing equipment is available to do the job. To satisfy this demand, a urea formaldehyde adhesive has been perfected which will develop sufficient cure after ten minutes under pressure to permit satisfactory handling. The adhesive is supplied in two parts; one part consisting of the resin itself which is spread on one of the surfaces to be glued, and the other part consisting of the catalyst which is spread on the second mating surface of the joint. Clamping of the assembled joint must be done rapidly since the hardening of the glue line starts immediately after the two mating surfaces have been brought into contact. This formulation has found many uses in the gluing of such items as bowling pins, laminated shoe lasts, and furniture items. An interesting application of the fast-curing adhesive is the manufacture of a two-ply veneer corrugation suitable as core material for building construction panels.

There are other adhesives besides urea formaldehyde for moisture resistant joints such as casein and blood derivatives, but they are today pretty much the same materials which were available during World War II. Casein glue has found an important use in the fabrication of large structural members which are glued under comparatively low temperature conditions. On-the-job gluing of prefabricated house assemblies has been done to a large extent with casein glues.

Adhesives for Fully Waterproof Joints

In periods of preparedness and mobilization, the greatest demand is for adhesives which will produce fully waterproof joints. Part of this demand is attributable to the sever exposure conditions to which the glued products are subjected. The other reason for this increased demand is the tendency of specification writers to incorporate the best possible adhesives for all defense production items. While it is, of course, desirable to use the best available adhesives for war production, in certain instances joints which are of low moisture resistance are perfectly satisfactory, and in these instances, use of a somewhat less water-resistant glue would help the overall supply and demand picture.

One of the developments in the field of fully waterproof adhesives which deserves consideration is the use of different types of acid catalyst with phenolic resin. Formulations of this type are now available on the market which will produce fully waterproof, exterior grade, cold-pressed plywood after 8 to 12 hours under pressure at 75 deg. F., and a subsequent conditioning period of approximately 72 hours. This same type of adhesive can be used for assembly gluing. Because of the action of the hardener which promotes the rapid curing, it is necessary to exercise a certain amount of care in the timing of the assembly operations and the working life of the mixture. There are probably a number of applications where use of the acid-catalyzed phenolic will relieve the demand for the more conventional adhesives used to develop this quality of joint.

Phenolic resins which are used predominantly in the manufacture of hot-press waterproof plywood, are pretty much the same adhesives which were used six years ago. Of course, as in any progressive industry, the adhesive manufacturers have incorporated refinements in their phenolic adhesives which improve their handling characteristics and decrease the unit cost of a glue line.

The development of so-called intermediate-temperature phenolics which are suitable for many applications and have been used extensively for marine laminating has not been extensive in the period under consideration. The principal reason for this is that increased acceptance of the resorcinol formaldehyde adhesives has decreased the interest in modified phenolics.

The principal advantage of the resorcinol adhesive over the modified phenolics is the lower curing temperature that is necessary to achieve the required amount of durability. Most of the resorcinol adhesives available on the market today, however, have been modified in the interest of cost, from the original almost pure resorcinol formaldehyde combinations by the addition of varying amounts of phenol.

The successful use of resorcinol adhesives during the latter part of World War II has pretty well established this material in the fabrication of items where hot-press temperatures are not practical. In the period following World War II when only a minimum of work was performed for the Armed Forces, the resorcinol adhesives were in little demand principally because their comparatively high cost prohibited their use in any but the most exacting applications. As a consequency of this lack of demand, comparatively few outstanding developments in resorcinol glues have taken place. One noteworthy development was the use of hardeners which did not release irritating odors. A prominent adhesive manufacturer has on the market today, a resorcinol glue which, when mixed with a special catalyst produces a minimum of irritating fumes.

In the gluing of large members, lack of irritating fumes is desirable from the standpoint of the welfare of the workmen. Most of the resorcinol adhesive available today, however, can be used without any danger to the workman, if proper ventilating facilities are provided.

The few preceding comments on adhesive developments since World War II concern themselves to a large extent with adhesives which are available immediately for a production purpose. There are undoubtedly a number of developments in the laboratories of various adhesive manufacturers which may eventually provide the fabricating industry with the ideal combination of fully waterproof joints at very low cost.

The history of the adhesive industry has shown that the intensity of effort which is devoted to research and development during periods of preparedness can often produce outstanding results in a very short time as compared to the many years required to achieve the same results under peacetime conditions.

Supply of Adhesives for Defense Production

Any prediction of the availability of adhesives for defense production is a precarious proposition because of the many intangibles which are involved. Even if precise statistics on adhesive production were available, it would be necessary to know how much of the adhesive supply would be used in civilian production and how much for defense production before an intelligent evaluation of the whole problem could be made. Unfortunately, this proportion of use is very indefinite.

Some general comments on the availability of adhesives based on the production capacities of the chemical manufacturers and the requirements of the adhesive-using woodworking industries at the time of writing may be worth while. Changes in the system of allocation and world conditions may make any of the subsequent comments obsolete overnight.

The Defense Order system of priority established by National Production Authority is designed to channel scarce materials into defense production. In actual practice, the broad coverage of this system often makes a DO rating on an order of little practical significance in being able to obtain critical materials. Part of this confusion is attributable to lack of control on the raw material manufacturer and part to the absence of a priority system to distinguish the importance of the different DO orders.

In the last war the distribution of adhesive materials was controlled by the War Production Board. The individual user was required to apply to the War Production Board for his needs, stating his inventory on hand, his end use, the amount required and the source from which he wished to purchase the material. The War Production Board would then notify both the customer and supplier of the amount allocated to him for a given month. This procedure worked out reasonably well throughout the last war and a somewhat similar procedure probably will have to be worked out for the current defense effort.

Animal glue, both hide and bone, are now critical. While DO orders are not required to obtain animal glues, this type of designation is definitely helpful especially when the orders are larger than normally supplied by the adhesive manufacturer. One of the important reasons for this condition is that a very large portion of the animal glue manufactured is used by industries other than woodworking and these other users of the glues have greatly increased their production. The prospect on the availability of animal glue is that until a more definite allocation procedure is established, its procurement is going to be progressively more difficult.

The availability of polyvinyl acetate emulsion glues is extremely critical and DO orders are definitely required to purchase substantial quantities. The principal reason for this rather surprising shortage is that the raw materials used in the manufacture of this type of adhesive are in great demand for uses other than as adhesives.

In general, the availability of urea resins is good. The high production of this adhesive makes it possible for the supply to keep up with the demand. How long this happy situation will continue is unknown but shortages in acids used for catalysts and in formaldehyde which seem to be developing, indicate that it probably will not be long. If the conditions prevailing in World War II are any indications, furniture and allied civilian production will not receive all the urea formaldehyde adhesives they would like to have, but they will receive a fair percentage of their needs.

The availability of phenolic and especially resorcinol adhesives is critical. DO orders are preferred for phenolic resins and are essential to get resorcinols in any volume. The reason for this scarcity is apparently intimately tied in with the country's benzene production capacity. The present method of manufacturing benzene is tied in with the coke phase of steel manufacture, and consequently, production of benzene is pretty much at its peak. In order to increase the production of benzene, new sources of supply must be developed. Apparently, the most practical way of accomplishing this is to manufacture the benzene from petroleum. While the process has been technically perfected, to develop it to the point where it can compete with benzene manufactured from coal will require a government subsidy. This subsidy is supposed to be forthcoming this year. The plans of the National Economic Resources Board call for an increase in this year's production of benzene from about 100,000,000 gallons to 200,000,000 gallons.

When the increased production of benzene is actually achieved, the availability of phenol and resorcinol adhesives will be considerably improved. In addition, when the mobilization effort really gets rolling, much of the demand for phenolics for non-

essential items like molded toys will be decreased, and consequently, a larger quantity of material will be released for manufacturing into adhesives.

The principal reason that phenolic adhesives are somewhat less critical than resorcinols is that since 1945 the country's phenol production has approximately doubled, while the production of resorcinol has remained about the same and practically all of this limited production is handled by one company. With the proportional allocation of raw materials, in this case, benzene, it is readily seen that the resorcinol adhesive manufacturer is not in a good position to meet the demand placed on him.

Use of Substitute Materials

As the country's preparedness effort increases it will become necessary to compromise on the durability of the glued joints obtained. There are two general ways in which this can be accomplished; both deserve consideration.

Most of the workmanship and materials in items for defense production are controlled by government specifications. A review of these specifications will undoubtedly result in a clarification of the adhesive needs of the country. There are many instances where the durability required of the item under consideration may well permit the use of an adhesive which has a lower amount of moisture resistance and is still perfectly adequate for the job. The Armed Forces realize the need for such a review and some progress has been made in making an intelligent appraisal of the specifications.

The other method of relieving the scarcity of adhesives will be the use of new substitute materials. During World War II the use of intermediate temperature phenolics and later resorcinols made possible the extensive marine laminating program which was so helpful to the war effort. Similar developments may take place in the current mobilization period.

Any substitute adhesive material should be thoroughly evaluated before it is placed in production. To accurately evaluate a new adhesive properly, trained personnel must be available both on the staff of the adhesive manufacturers and the users. The former, by and large, do have this type of personnel, but with the latter, technically-trained personnel is the exception rather than the rule. The user of the adhesive must make a special effort to either hire technically-trained men or to have competent men already on his staff—trained in the basic methods of evaluating and using glues. Training courses of this nature are now available to men of the woodworking industries.

Conclusion

With intelligent planning of the country's production and with the help of the research facilities of the adhesive industry enough adhesives for the forest products industries will eventually be obtained to satisfy the demand. The country today has a much higher production in synthetic chemicals than it did during World War II and the plans of many adhesive manufacturers are to greatly expand their production. In addition, we have a diversity of adhesives which permits us to manufacture a much wider range of wood products suitable for the needs of the Armed Forces than we had during most of World War II.

Discussion

R. L. Hiller (American Cyanamid Company): The Speaker pointed out that one of the post-war developments had been the development of a low-solids resin making it possible to ship liquid resins by tank car. It is questionable whether this was the reason for tank car shipments. High-solids resins are being shipped by tank car very successfully and actually, the major portion of the development of low-solids resins was a result of tank car shipments and not the paramount driving force for such shipments. The use of tank cars as a means of shipping ureas was one of economics; namely, reduced manufacturing, container, shipping, and handling costs.

In 1945, about 30,000,000 pounds of dry urea and melamine resin adhesives were produced; in 1950, over 75,000,000 pounds were produced. These figures do not show the full story as in 1945 a large proportion of the adhesives sold were in powder form. In 1950 the largest percentage sold was in liquid form containing from 47 to 80 percent solids and, therefore, considerably more resin on a basis of actual pounds sold was shipped than the figures indicate. These figures do establish one fact—that the resin adhesive suppliers have substantially increased their capacity. Actually, the supply of resin adhesives available for civilian consumption is going to be controlled to the greater extent by two factors; namely, raw material supply and government control.

In the case of urea adhesives, the two controlling materials are urea and formaldehyde. Urea production capacity has been increased substantially by the one established manufacturer and there is now another domestic producer. Foreign urea is also available from time to time. Formaldehyde also is produced in considerably larger quantities than in 1945. Melamine crystal production is, likewise, increasing.

Urea resin products are used in a variety of products and applications are widespread in the paper, foundry, textile, and finishing fields. Melamine products have a similar widespread application. It therefore resolves into a condition where production capacity within the limits of material supply is controlled by what the Government tells the adhesive supplier he can produce for the civilian woodworking industry.

TECHNICAL SESSION XI—Fri., May 11, 1951, 2:00 P. M.

General Subject: Improved Kiln Drying

Co-Sponsor: Keystone Dry Kiln Club

Chairman: Newell A. Norton

How to Formulate Dry-Kiln Schedules

RAYMOND C. RIETZ, *Chief, Division of Timber Physics, Forest Products Laboratory,*[1] *Forest Service, U. S. Department of Agriculture, Madison, Wisconsin*

THE efficient operation of a lumber dry kiln depends to a considerable extent on the use of drying schedules that, when closely adhered to, reduce over-all kiln time and minimize seasoning degrade. Forced-air-circulation dry kilns, susceptible to good control of dry and wet-bulb temperatures, can be operated to increase production at reduced costs if the kiln operator is familiar with the drying characteristics of the wood and uses severe drying conditions when the likelihood of damaging the stock no longer exists.

As kiln time and seasoning loss determine the general cost of drying, it is essential that the drying schedule be so patterned that the drying conditions are effective in reducing kiln time and do not cause excessive surface checking, end splitting, or honeycomb. The objective of much research at the Forest Products Laboratory on the kiln drying of wood has been to determine just how fast, yet safe, a schedule can be formulated for any one species or item.

General experience has indicated that, in drying hardwoods, green from the saw, moderately low temperatures must be used in the beginning, but, as the stock dries, the dry bulb-bulb temperature can be increased step by step. A similar pattern of reduction in relative humidity as the stock dries is generally known to be effective. Obviously, many combinations of dry-bulb temperature and relative humidity, and rates of increase of temperature reduction in relative humidity are conceivably suitable for any one species or item. The problem is to formulate a pattern of a schedule which involves temperature and relative humidity changes that appear to be adapted to practical kiln operation, yet are based on factors related to the causes of seasoning degrade. If moderate dry-bulb temperatures are maintained until all of the free water has been evaporated they can be elevated to rather high values without causing honeycomb. Thus, accelerated drying through the use of high dry-bulb temperatures is limited to the evaporation of hygroscopic water except in those species that do not readily honeycomb. We now recommend that final dry-bulb temperatures as high as 180° F. be used to kiln dry hardwoods. In some instances, however, much higher dry-bulb temperatures are used to reduce kiln time, particularly when the item does not require maintenance of maximum strength properties. The successful use of these high final dry-bulb temperatures, however, is dependent upon assurance, through good sampling, that these high temperatures not be used until practically all of the pieces in the kiln charge no longer contain free water.

In kiln drying green hardwoods, high initial relative humidities must be used to prevent the development of an excessive amount of end checking and splitting or surface checking. In developing a fast schedule, the problem is to set up a technique to determine when it is safe to reduce the relative humidity. Obviously, it is desirable to maintain as low a relative humidity as possible. Studies have shown that, when hardwoods are case-hardened, the relative humidity can be reduced and new surface checks or end checks will not develop. If a dry kiln were to be operated on the basis of the development of case-hardening in relation to relative humidity control, the kiln operator's job would be rather difficult. As the temperature schedules are based on moisture content, it is desirable that the relative humidity schedules also be based upon moisture content. Thus, in drying green stock the relative humidity can be lowered after about one-third of the water has been evaporated.

These concepts of accelerating the drying of wood by elevating dry-bulb temperatures and reducing the relative humidity when damage through honeycomb or surface checking is no longer likely are incorporated in the Forest Products Laboratory's new recommendations for drying schedules. The dry-bulb recommendations are separated from the humidity recommendations, so that the concepts of accelerated drying can be employed advantageously. This splitting up of the schedules may cause some confusion, but, in the long run, we believe that material benefits in reduced kiln time will be gained without increasing seasoning degrade. Forest Products Laboratory Report No. D1791 presents these new drying-schedule recommendations, and it incorporates practical suggestions for equalizing and conditioning, so that the kiln operator can produce uniformly dried, stress-free stock.

[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

Some Characteristics of Brazilian Parana Pine Affecting Its Use for Millwork

MAXON Y. PILLOW, *Technologist, Forest Products Laboratory,*[1] *Forest Service, U. S. Department of Agriculture*

A softwood from Brazil commonly called Parana pine has many desirable characteristics but compression wood causes difficulty in the form of warping. Detection of compression wood and kiln drying by accelerated schedules as well as at moderate temperatures are described.

Introduction

A SOFTWOOD from Brazil being imported in large quantities is Brazilian araucaria (*Araucaria angustifolia* (Bert) O. Kuntze.), commonly known as Parana pine. Lumber of this species has many desirable characteristics. It has attracted considerable attention because of its use in general millwork and for some more specialized purposes, for example, as wood for picture frames and venetian blinds.

An appreciable tendency to warp, however, has been reported for some pieces of Parana pine. Many requests have been received by the Forest Products Laboratory for information on the characteristics and kiln drying of Parana pine. The large numbers of requests has indicated a need for further investigation of the behavior of this wood in its important uses.

The purpose of this work on Parana pine was to assemble the information already available, to determine some characteristics of shrinkage that might cause kiln-drying defects and warping, and to observe behavior of the lumber during manufacture of millwork and other products. Some information came from 15 or more years experiences with this lumber by a few millwork manufacturers. In addition, some users cooperated by providing material for laboratory investigations and facilities for observing Parana pine lumber during commercial kiln drying and the manufacture of millwork. Thus the Forest Products Laboratory was able to examine the characteristics of Parana pine by combining the information obtained from observing commercial practices with that gained from laboratory procedures.

General Characteristics of the Lumber

Parana pine is a softwood or conifer, although not a pine. Its texture is uniform, with little contrast between springwood and summerwood. The annual rings, however, usually are clearly marked by a few narrow fibers at the outer boundary of the rings, so that they are seen readily on planed surfaces. The wood does not contain resin ducts or exude resin as do native pines, but some resinous material is included in the wood. This material has been reported to gum up sandpaper to a much greater extent than does a nonresinous wood, such as basswood.

Sapwood of Parana pine is of white to cream color, while heartwood is brown, but the color sometimes merges with shades of gray. Outer heartwood frequently has red streaks, and although the identity of these has not been determined, they do not appear to be associated with decay. The brown to gray colors of heartwood bleach rapidly with commercial hydrogen-peroxide bleach, but the red streaks are affected only slightly by this treatment.

Parana pine lumber received in this country has consisted mostly of clear boards. Some of these have been entirely sapwood; others have contained different proportions of sapwood and heartwood. Knots were present in relatively few boards and were usually small. A limited number of other boards had the appearance of including the overgrowth of knots. The boards usually were 10 to 20 feet long and varied in width from about 6 to 14 inches. Lumber in 4/4-, 5/4-, 6/4-, and 8/4-inch thickness has been imported into this country during the past year.

Physical properties were determined for Parana pine by the Institute of Technological Research, Sao Paulo, Brazil.[2] The average density and shrinkage properties of Parana pine are shown in Table 1 in comparison with some of our native species. Determination of strength properties by the Institute indicated that Parana pine has properties similar to those of coast-type Douglas-fir of this country.

Some determinations were made on shrinkage and specific gravity of Parana pine lumber that was supplied by domestic plants using this material for millwork. Average tangential shrinkage of flat-sawed boards was somewhat smaller than that reported from Brazil,[2] being 7.6 percent as compared with 8.4 percent. This smaller average tangential shrinkage indicated the presence of compression wood in some specimens, as compression wood is known to have smaller transverse shrinkage than normal wood. Average specific gravity of normal Parana pine determined at the Forest Products Laboratory conformed closely with the average reported from Brazil,[2] being 0.45 and 0.44, respectively, based on green volume and ovendry weights.

The wood of Parana pine is reported to take and hold paint well and also to glue satisfactorily. It is reported to have low resistance to decay, and, therefore, it should be treated with preservatives for uses in which decay is a factor.[2] Some commercial experience has shown that Parana pine readily absorbs water-repellent preservatives such as are commonly

[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2] Brush, W. D. Brazilian Araucaria (Parana pine). U. S. Dept. of Agric., Forest Service. January 1945.

TABLE 1.—SOME PHYSICAL PROPERTIES OF PARANA PINE IN COMPARISON WITH SOME NATIVE SPECIES

	Specific gravity[1]	Weight per cubic foot[2] Pounds	Shrinkage		
			Radial Percent	Tangential Percent	Volumetric Percent
Parana pine[3]	0.44	33	3.7	8.4	13.5
Douglas-fir[4,5]	.45	34	5.0	7.8	11.8
Ponderosa pine[5]	.38	28	3.9	6.3	9.6
Loblolly pine[5]	.47	35	4.8	7.4	12.3
Shortleaf pine[5]	.46	36	4.4	7.7	12.3

[1]Based on volume when green and oven-dry weight.
[2]At 12 percent moisture content.
[3]Bulletin No. 24, Institute of Technological Research, Sao Paulo, Brazil.
[4]Coast-type Douglas-fir.
[5]Technical Bulletin No. 479, U. S. Dept. of Agric., Washington, D. C.

used for millwork.[3] A few 3-minute dipping tests made at the Forest Products Laboratory showed moderately large absorptions of the solution but practically no differences in the amounts absorbed by light-colored sapwood or dark-colored heartwood. This moderately large absorption, however, still was below the amount that might be expected to interfere with painting of dipped sash made from Parana pine.

Warping Caused by Compression Wood

Warping of kiln-dried Parana pine was the principal defect encountered when large amounts of the lumber were recently observed. The warping occurred when some boards were planed, ripped, or resawed, although, in general, much of the rough lumber was reasonably straight. The surface-wise bowing and edgewise crooking resulted from internal stresses along the grain. A common cause of such stresses is the inherently smaller shrinkage along the grain of normal wood compared with greater longitudinal shrinkage in the abnormal type known as compression wood. The action of longitudinal stresses that resulted from differences in shrinkage of normal wood and compression wood in a Parana pine board is shown in Fig. 1.

Longitudinal shrinkage of Parana pine was determined for specimens approximately 1 inch by 1 inch in cross section cut consecutively across boards. Some of these boards contained compression wood while others contained practically all normal wood. Based on soaked length, the average longitudinal shrinkage of compression wood specimens was 0.55 percent compared with average shrinkage of normal wood of 0.14 percent. Longitudinal shrinkage of compression wood varied from 0.158 to 1.341 percent, and that of normal wood from 0.074 to 0.273 percent. The exceptionally large variations in shrinkage of compression wood were related to the wide variations in severity in the forms of compression wood, which ranged from borderline forms that closely resembled normal wood to pronounced forms with readily visible abnormal structure.

Microscopical examinations made on samples of Parana pine in the laboratory and ordinary visual examinations of lumber at millwork plants showed that the presence of compression wood was closely associated with warping. Pieces of lumber that were warped frequently had compression wood on the concave side and normal wood on the convex side of the curvature. This action of compression wood

Fig. 1.—Action of longitudinal stresses in a Parana pine board that had been ripped lengthwise; the board contained both normal wood having relatively small shrinkage and compression wood having exceptionally large shrinkage along the grain.

of Parana pine was the same as had been found in native species of softwoods.[4] The tendencies to cause warping increased with the relative amounts of the compression wood and the severity of its different forms.

Some boards contained large amounts of compression wood, mostly near one surface so that it caused bowing (Fig. 2). In other boards, relatively smaller amounts of compression wood were present, usually in streaks that included certain annual rings (Fig. 3). The number of boards that contained compression wood varied widely in the lots of lumber that were examined. Compression wood was found in about one-fifth of the boards in some samples, whereas in other samples, it was present in two-thirds of the boards. Such wide variations in amounts and differences in severity of warping of

[3] Browne, F. L. Preservative Treatment for Window Sash and Other Millwork. Forest Products Laboratory Report No. 919. Revised 1945.

[4] Pillow, M. Y. Compression Wood Cause of Bowing and Twisting. Wood Working Industries. November 1930.

Fig. 2.—Parana pine board with bowing (left) caused by compression wood on nearly all of the entire concave surface (middle), while convex surface (right) is essentially free from compression wood.

Fig. 3.—Pieces of Parana pine containing streaks of compression wood (indicated by arrows) that is recognizable from its deeper color.

the compression wood resulted in wide differences in behavior of lumber being manufactured for millwork and other products.

Some air-dried boards were observed to be warped (Fig. 4), but much of the rough Parana pine lumber was reasonably straight even after kiln drying. Nevertheless, when such lumber was ripped, many of the pieces from boards that contained compression wood were severely warped, so that they were not usable as millwork (Fig. 5). Surfacewise bowing or edgewise crooking or both occurred when some boards containing much compression wood were ripped into narrow strips (Fig. 6). On the other hand, only some of the pieces ripped from boards with small amounts of compression wood tended to be warped and all pieces from boards without compression wood were essentially straight (Fig. 7). These observations showed the close relationships existing between the presence of compression wood and warping in Parana pine, and also between increased severity of warping and increased amounts of compression wood.

Kiln Drying of Parana Pine

Kiln drying is necessary for many of the millwork uses for which Parana pine is being imported. Much of this lumber has been received in this country partly air-dried to moisture contents of 15 to 25 percent of the oven-dry weight; however, a few lots have been reported to include some boards with 50 to 70 percent moisture content.

Parana pine seems to have acquired a reputation for being more difficult to kiln dry than native softwood species. This reputation appears to have resulted from the warping in some boards that included compression wood. Commercial kiln drying of this species has tended toward the use of moderate temperatures in an effort to reduce the seriousness of warping. It was learned that some Parana pine has been commercially kiln dried with reason-

Fig. 4.—Air-dried Parana pine board showing severe bowing that was the result of larger amounts of compression wood on concave side than on convex side.

ably satisfactory results at temperatures of 150° to 170° F. (Table 2). It is also reported that the

TABLE 2.—SCHEDULE COMMONLY USED FOR COMMERCIAL DRYING OF PARANA PINE LUMBER

Moisture content				
From Percent	To Percent	Dry bulb °F.	Wet bulb °F.	Relative humidity Percent
45	40	140	132	80
40	30	145	135	75
30	25	150	137	70
25	20	155	136	60
20	15	160	135	50
15	10	165	127	35
10	Final	170	116	20

British, who have used this wood for many years, commonly kiln dried it at even lower temperatures of 110° to 135° F.[5]

Recent work was done at the Forest Products Laboratory on the effects of warping in Parana pine lumber. One lot of partly air-dried boards was experimentally kiln dried at moderate temperatures

[5] Kiln Drying Schedules. Leaflet No. 42, Forest Products Laboratory, Dept. Sc. and Ind. Res. Princes Risborough. December 1948.

Fig. 5.—Serious warping in pieces of Parana pine ripped from a board with a large amount of compression wood. This abnormal wood appears as the dark-colored part at the far end of the pieces.

with an initial dry-bulb temperature of 155° F. and a final temperature of 170° F. (Table 2). For comparison, another lot of end-matched pieces from the same 2-inch lumber was kiln dried at higher temperatures with an initial temperature of 190° F. and a final temperature of 200° F. The total time in the kiln of these two charges included time for equalization and conditioning to relieve case-hardening. The two kiln-time periods were, respectively, 9¼ days for the pieces dried with moderate temperatures and 6¼ days for pieces dried at the higher temperatures. After all the boards were kiln dried, they were resawed and planed on both surfaces. Examinations were then made to compare the amount of warping in the two lots of boards that were kiln dried, respectively, at moderate and at high temperatures.

Examinations of all the boards showed that both lots were about equally free from transverse case-hardening stresses. A tendency of both lots to cup slightly after being seasoned, however, indicated that the conditioning treatment should have been continued for a somewhat longer time. Although slight warping occurred in certain boards, this defect was equally common in both lots and was directly related to the incidence of compression wood.

Fig. 6.—Warping in all pieces ripped from a Parana pine board containing a large amount of compression wood.

It was concluded from examination of the boards in these experimental kiln runs that neither kiln-drying treatment was superior to the other with respect to warping. This work confirmed the beliefs that warping was directly related to the inherent large shrinkage along the grain of compression wood, and that tendencies of certain pieces to warp were not affected by kiln-drying temperatures. The use of relatively high temperatures, nevertheless, had the advantage of shortening the time required for kiln drying Parana pine lumber. There was shown to be a need, however, for equalization in order to produce uniformly dried lumber and for conditioning to relieve transverse case-hardening stresses. This need is apparent even though these equalizing and conditioning treatments cannot be expected to relieve many of the longitudinal stresses that are caused by the inherently large longitudinal shrinkage of compression wood.

A recommended schedule of high temperatures has been developed for Parana pine for the purpose of accelerating kiln drying when this is desirable. It should be remembered, of course, that lower temperatures can be used. The schedules in Table 3 for accelerated drying are taken from schedules developed at the Forest Products Laboratory in 1951.[6]

When the stock is green, the first change in the wet-bulb depression is made at an average moisture content of 40 percent. If the stock is air dried, use an initial wet-bulb depression as indicated for the average moisture content of the stock. For example, if the average moisture content is 23 percent, the initial wet-bulb depression is 20° F. for 1-inch stock and 15° F. for 2-inch stock.

These schedules are recommended as a basis for developing a time schedule which can usually be used for kiln drying softwoods.

Equalization and conditioning treatments are frequently given in the final stage of drying to reduce the variation in moisture content between boards, to establish a uniform moisture content within each board, and to relieve case-hardening stresses in both the transverse and longitudinal directions. The conditions to establish within the kiln during these treatments are dependent upon the final moisture content desired. A general guide for equalizing and conditioning Parana pine is as follows:

(1) Dry the *driest* sample in the kiln charge to an average moisture content 2 percent below the desired final average moisture content.

(2) As soon as the *driest* sample reaches the value specified in (1), establish an equilibrium moisture content condition in the kiln equal to that value. This is known as the equalization treatment.

(3) Allow the kiln charge to equalize until the *wettest* sample in the charge reaches the desired final average moisture content.

(4) As soon as the *wettest* sample reaches the value specified in (3), place the kiln charge on a conditioning treatment at an equilibrium moisture

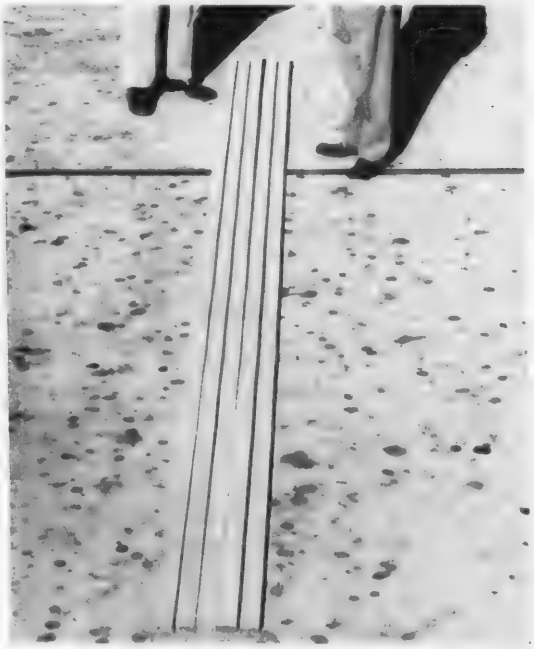


Fig. 7.—Practically straight pieces ripped from a Parana pine board essentially free from compression wood

[6] Torgeson, O. W. Schedules for the Kiln Drying of Wood. Forest Products Laboratory Report No. 1791. February 1951.

TABLE 3.—ACCELERATED SCHEDULES SUGGESTED BY THE FOREST PRODUCTS LABORATORY FOR 1-INCH AND 2-INCH GREEN AND AIR-DRIED STOCK

Moisture content		Dry-bulb temperatures	Wet-bulb temperatures		Relative humidity	
From Percent	To Percent	°F.	1-inch lumber °F.	2-inch lumber °F.	1-inch lumber Percent	2-inch lumber Percent
			For green stock			
Initial	40	180	170	173	79	85
40	35	180	166	170	72	79
35	30	180	160	165	62	70
30	25	190	155	165	43	56
25	20	190	140	150	28	37
20	15	200	150	150	30	30
15	Final	200	150	150	30	30
			For air-dried stock			
Initial	30	180	170	173	79	85
30	25	190	176	180	73	80
25	20	190	170	175	63	71
20	15	200	165	175	44	57
15	10	200	150	160	30	39
10	Final	200	150	150	30	30

content of 2 to 3 percent above the highest desired final average moisture content.

(5) Allow kiln charge to condition until the stock is free of case-hardening.[7]

After a number of charges have been satisfactorily kiln dried, equalization and conditioning treatments can be put on a standardized time basis.

Detection of Compression Wood

Compression wood in Parana pine can be detected by its yellow to brown color in contrast to white to cream color of normal sapwood. Compression wood also appears to be denser and the annual rings appreciably wider than adjacent rings of normal wood. Much of the compression wood observed in Parana pine at millwork plants appeared in streaks that were readily detected on surfaced lumber by their characteristics of color and texture (Fig. 3). Warping of some pieces also indicated the presence of compression wood in rough, kiln-dried lumber.

Experience has shown that by segregation of bowed and crocked rough boards after kiln drying the remainder of the lumber when ripped into narrow pieces showed only slight warping in a relatively few pieces. The segregation excluded most of the pieces with large amounts of compression wood, and the excluded material was usable in the form of small pieces in which some warping was not a serious defect.

The characteristics that signify the presence of compression wood in Parana pine are:

(1) On planed surfaces of sapwood in boards, compression wood has a yellow to brown color, in contrast to white or cream-colored normal wood.

(2) In heartwood, differences in color between compression wood and normal wood are small. Compression wood, however, usually is deep brown in color, while normal heartwood is grayish-brown.

(3) Compression wood tends to be present in certain growth rings and absent in adjacent rings, so that streaks of this abnormal type of wood and of normal wood frequently are present in the same board.

(4) Texture of compression wood appears to be harder or more hornlike than that of normal wood, and the growth rings of compression wood are wider. These characteristics are seen readily on smoothly cut end grain of Parana pine boards.

(5) Surfacewise bowing is the most common type of warping. It can be seen even when slight by turning boards edgewise and sighting along the upper edge to determine whether they are straight or warped.

(6) Edgewise crooking is not so common in partly air-dried lumber as it is in kiln-dried lumber. In the latter, crooking can be seen by sighting along the edges of boards as they lie flatwise on a pile of lumber. Even though the crook is less than an inch in a 16- to 18-foot board, it indicates the presence of compression wood.

(7) Relatively long splits, 1 foot or more in length in comparison with shorter end checks, are indications that compression wood is present in Parana pine boards (Fig. 3).

Inspection of parana pine for compression wood and the elimination of affected boards are recommended for all major uses of this species of wood. This will help to minimize warping in boards being used for millwork.

The lumber should be examined by inspectors who have become familiar with characteristics of color, texture, and the action of compression wood in causing warping. These examinations can be made during the handling and grading of lumber, along with examinations for other defects not permissible in certain kinds of millwork. There are limits within which it is practical to detect compression wood in Parana pine lumber. Small amounts of compression wood, in fact, are not likely to cause serious warping in finished pieces that are satisfactorily straight, that is, straight enough so that they can be readily assembled as sash, frames, or trim. On the other hand, lumber that is warped badly when it is ripped is impossible to use satisfactorily.

[7] Forest Products Laboratory Technical Note No. 213.

1951 ANNUAL BUSINESS MEETING

The meeting, held in the Betsy Ross Room of the Benjamin Franklin Hotel, Philadelphia, Pennsylvania, was called to order by President Hamilton at 8:30 P. M., Tuesday, May 8, 1951.

1. Minutes of Previous Meeting

Announcement was made that the minutes of the preceding annual business meeting, held in Portland, Oregon on June 27, 1950, had been approved by the Executive Board and published in the Proceedings of the 1950 National Meeting.

2. Report of the Executive Secretary

During the fiscal year 1950 the net paid-up membership increased from 2022 to 2178. This has been increased to 2267 as of May 1. An analysis of members by types, as of March 31, breaks down to 1867 voting and associate members, 98 supporting members and 213 student members. The Society now has members in all 48 states, all possessions, Puerto Rico, all provinces of Canada and 25 foreign countries, the republic of Indonesia being the latest foreign country added to the roster.

The number of Sections has increased from 10 to 11 with the addition of the Pacific Southwest.

During the 1950 fiscal year the National Office underwent several major changes. Following the resignation of former Secretary-Treasurer, Charles Van Hagan, George M. Hunt served temporarily as Acting Secretary-Treasurer without pay. During his several months' administration, much work preparatory to the 1950 Annual Meeting and Proceedings was accomplished, and the groundwork laid for gains both in services and finances which were subsequently attained. The present staff and Executive Board join the Society in extending their grateful appreciation for this guidance to Mr. Hunt and his associates in the U. S. Forest Products Laboratory.

On July 16, 1950 the present Executive Secretary, Frank J. Rovsek, officially assumed his duties in the National Office.

Cash on hand April 1, 1950 was $14,965.05. Total receipts during the fiscal year 1950 were $54,338.14. Expenditures were $42,386.49. Cash on hand at the end of the fiscal year (March 31, 1951) was $26,914.70. The Society's income was derived principally from membership dues, publications, advertising and meetings. The principal items of expense were for the operation of the central office, including salaries, stenographic service, communications, supplies, travel of executive officers and publications.

In addition to cash on hand, the Society has assets of $730.00 in accounts receivable and $1,650.00 in inventory (equipment, printed matter and stamps). Also on hand, conservatively valued, are 3,500 copies of Volumes 1, 2 and 3 (total) and 1,436 copies of Volume 4, plus a considerable quantity of reprints.

3. Auditor's Report

The auditor's report for the period April 1, 1950 through March 31, 1951 was read by Chairman L. Markwardt. On motion duly made and seconded, it was accepted. It was also moved, seconded and carried that the secretary publish future reports to the membership within a reasonable period prior to the Annual Meeting.

4. Review of Section Activities

One or more meetings during the year were held by 10 of the present 11 Sections of the Society. The year also witnessed the largest-attended Section meetings in FPRS history, with upwards of 400 persons attending both the Midwest Section meeting at Rockford, and the Northeast Section meeting at Gardner last fall. Our newest Section, Pacific Southwest, received its charter during the year and has held two meetings in the Los Angeles area. Our former Lower Michigan Section has been expanded in its scope of operations and re-named the Great Lakes Section, holding a very successful meeting this past month.

Much interest is being displayed in the establishment of a potential Section to serve the Ohio Valley area between Louisville, Cincinnati and adjacent wood centers. It is hoped that such a Section will become our 12th during the 1951 administration.

Particularly to be singled out for outstanding Section service are Northeast, Virginia–Carolinas and the Midwest, all of whom have published Section preprints of meeting papers, and bound Section proceedings during the year, a service which in the ensuing year will become available to all of our 2,200 FPRS members.

In summary it may be said that almost without exception our 11 Sections have made splendid progress in meeting activity, attendance and membership.

5. Report of the Publications Committee

The Committee began the period after the Portland meeting without the services of its chairman, Dr. Frank Kaufert, who, because of a by-law limiting continuous service as a committee chairman to three years, had to retire. We gratefully acknowledge the excellent leadership of Dr. Kaufert. The rest of the committee remained intact and the new chairman assumed his duties on October 1, 1950.

Early in 1950 the Publications Committee recommended to the Executive Board that the then exist-

ing arrangements for publication be continued for the time being rather than set up a separate Journal for the Society. The desirability of a separate publication was recognized by all members but it was felt that until our membership was greatly increased and was financially able to assume the cost of such a publication, it would be unwise to move ahead on this. The question was, however, left open.

Last October your Executive Board deemed it advisable to expand the Society's publications to include a News-Digest and an All-Section Proceedings. Several copies of the monthly News-Digest have appeared and any comments from the membership will be welcomed. The second unit of the expansion program has not yet gone to press.

At present we are reassessing our publication needs and objectives. We are not ready now to make recommendations. There is, of course, a diversity of opinion in this matter. Suggestions which you may wish to present to committee members will receive thorough consideration.

The procedure used in handling papers for the 1951 Annual Meeting was similar to that for the preceding meeting at Portland except that assignments for review of articles were made on an individual basis rather than for an entire session. When necessary, committee members enlisted the aid of specialists in a particular field. Staff members of the Forest Products Laboratory were especially helpful in this regard and our thanks go to any who have assisted us.

Under the system employed, papers received by the Executive Secretary at Madison are sent to committee members for review according to assignments previously agreed on. After review and preparation of recommendations by committee members, or their colleagues, papers were sent to the chairman for consideration of comments, changes and recommendations relative to acceptance, and then returned to Madison.

The principal difficulty in this present setup is the failure of some authors to meet the deadline for receipt of their papers. In fact, about 15% of the papers never reached the chairman because they could not have been preprinted in time for the meeting.

In general, the caliber of the papers submitted was good; some were exceptionally well prepared. We appreciate any extra effort made by authors to ease our task by submitting well organized and well written articles.

Papers were carefully reviewed and promptly handled by all committee members. The chairman of your committee would like to commend all members for their excellent job and to thank them for their time. Also, the committee expresses its appreciation to Mr. Frank Champion, Mr. Donald Coleman, Professor Roy Carter, and to Mr. Frank Rovsek who aided us tremendously.

Respectfully submitted, E. A. Behr, J. B. Grantham, R. C. Rietz, F. F. Wangaard, I. H. Isenberg, *Chairman.*

6. Report of the Abstracting Committee

From correspondence received, plus statements I have had from members of the committee, it is evident that many of our membership do not regard too highly our present Abstracting service.

I have given this matter a good deal of thought. In the following I should like to set forth a 6-point program for the consideration of the members and Executive Board.

1. That a call be issued through the Monthly Bulletin for volunteers to abstract for the Society and that such volunteers indicate the journal or journals available to them.

2. That abstracts rather than summaries be prepared and that those accepted be given a subject number designation and indexed in a manner similar to the system employed by Biological Abstracts.

3. That these abstracts be published as a section of the Annual Proceedings where they will be in a permanent binding and thus always readily accessible.

4. That the abstracting committee consist of one man from each region and a chairman. The duties of the regional representative to collect and if necessary edit abstract prior to submission to the chairman whose responsibility will be to catalogue and prepare for final publication.

5. That a limited amount of money be set aside for the procurement of really outstanding journals not otherwise available.

6. That certain of the abstractors be associated with research laboratories or universities having libraries that are procuring technical bulletin series from the research centers of the "wood technological world."

Respectfully submitted, E. S. Harrar, *Chairman FPRS Abstracting Committee.*

Ensuing discussion developed that existing abstracting services are superior to those which the current limited organization of FPRS can offer. On motion duly made and seconded the report was accepted and returned to the committee for further study and recommendation.

7. Report of the Membership Committee

As authorized by the Executive Board a National Membership Committee has been formed. It is presently composed of the second vice president of the Society as chairman and a representative from each Section as follows: Pacific Northwest—A. C. Knauss; Northern California — J. C. Rowney; Pacific Southwest—J. R. Barnes; Inland Empire—T. C. Spaulding; Midwest—J. J. Allegretti; Virginia–Carolinas—R. G. Lenox; Deep South—W. Jeter Eason; Northeast—P. H. Graham; Florida–Georgia–Alabama—B. E. Anderson.

The function of this committee is to coordinate all membership activities of the Madison office and the local Sections. They are to work directly with the Executive Secretary in carrying on effective

(Continued on pages 318, 319)

Nails and Screws in Wood Assembly and Construction

E. GEORGE STERN, *Director, Virginia Polytechnic Institute Wood Research Laboratory, Blacksburg, Virginia*

Such information on the efficiency of nails and screws, as is summarized in the *Wood Handbook*, [1,30] was for many years the only technical data available to users of nails and screws. In many instances, this source was given little or no consideration; use of nails and screws was based on experience, tradition, and convenience.[2] Today, however, so much more is known about this field of fastening that anyone who doesn't use the available information is under a serious handicap.

The old-time attitude on the part of nail users led to little progress in the practice of fastening with nails and screws. However, eventually, as the result of the progressive outlook and ingenuity of a few forward-looking manufacturers, a new industry was developed: the mass-production of threaded nails. These improved nails have in many cases replaced wood screws, since the improved nails offer the advantages of common plain-shank nails, and approximate the holding power of wood screws. By eliminating a considerable number of production and service problems encountered with common nails and screws, these improved fastenings have given new impetus to certain industries. In many other fields, however, the improved nails did not come into common use until laboratory and field reports revealed that the improved nails result in a better product and in both direct and indirect savings.

Nail Design

Although the common plain-shank nail is satisfactory for many fastening purposes, a good deal of study has been directed to the problem of improving its efficiency by giving attention to the great number of variables possible in nail design and use.[3-6] However, the most significant recent advance in the field of nailing is the mass-production of threaded-shank nails, which was followed by a number of improvements in threaded-shank design.

For many years wire nails were commonly made with superficial indentations or "barbs" along the nail shank. Although these "barbed" nails were for a long time supposed to provide increased holding power in comparison with plain-shank nails, fully comparative laboratory data indicate that this is only the case under certain service conditions. The shallow indentations of the "barbed" nail provide a surface roughness which actually decreases the tight contact between nail shank and surrounding wood. On the other hand, properly designed, comparatively deep, fully annular or helical threads along the nail shank provide indentations into which the forcefully-separated wood fibers may penetrate and, thus, provide both frictional resistance and shear resistance to nail withdrawal.

If the shank threads are properly designed, the cantilevering wood fibers slide, during nail driving, over annular thread crests (Fig. 1, center) into the space between the thread crests where they hold the nail firmly since they cannot slip backward. Thus, only if forcefully damaged or decayed, can these wood fibers give way to the thread crests which are firmly embedded between the wood fibers during nail driving.

In the case of the properly designed helically threaded nail shank with a long lead, or large helix angle, (Fig. 1, left), the nail turns like a screw during nail driving. The thread crests work themselves into the wood by forming a thread, thus, allowing the nail surface to slide along the wood fibers during driving. If the helically threaded nail can turn backward freely, the friction between threaded nail shank and compressed wood fibers provides the resistance to axial withdrawal. If, on the other hand, the properly designed helically threaded nail with long lead cannot turn backward, the wood fibers which cantilever into the space between thread crests must be damaged or must deteriorate in order to decrease the nail-holding power.

A relatively new thread design is that of a nail having short-lead helical thread roots opposite the thread crests (Fig. 1, right). This results in a uniform cross-sectional shank area along the threaded shank length, hence, provides minimum cross-sectional stress variation during driving and while in use. Because of the small helix angle, this nail attains its withdrawal resistance in the same manner as does the annularly threaded type.

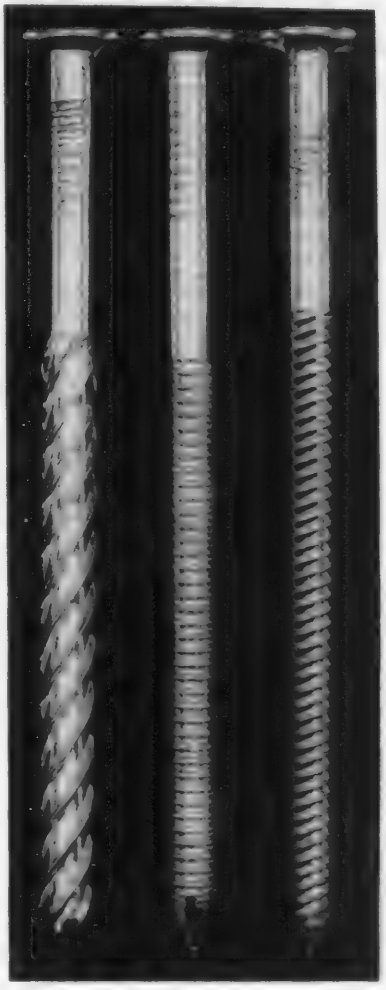


Fig. 1a—From left to right, 4" x 0.203" helically threaded *Screwtite* nail, annularly threaded *Stronghold* nail, and helically threaded *Stronghold Screwnail*, twice actual size.

From the preceding discussion, it follows that thread design is of prime importance in nail efficiency. If the threads are shallow, they may be less effective than if they are deep. On the other hand, a nail with indentations too deep is apt to buckle during driving and offers little resistance to shear and bending if laterally loaded. Thus, recent investigations indicate that the annularly threaded nail shank with rounded thread roots is considerably more effective than one with sharp thread roots. Similarly, a helically threaded nail shank with rounded thread roots may be less effective than one with flattened thread roots. The latter design is particularly effective because it makes possible a relatively sharp crest angle which results in a sharp thread in the forcefully-spread wood fibers and, thus, in increased friction between wood fibers and nail shank.

The importance of the properly designed thread crest led to the introduction of annularly threaded shanks with primary and secondary thread crests (Fig. 1) which, if of proper proportions, are the reason for maximum holding power of this nail type among threaded-shank nails. Both the annularly and helically threaded nails display this double-crest design.

A slight taper of the threaded-shank section of the nail (Fig. 2) can considerably increase the nail efficiency since the grip of the thread crests and, consequently, the frictional resistance of the driven nail increases with increase in nail penetration. This taper thread is applicable to both the annularly and helically threaded nail-shank designs, and promises to increase the use of threaded-shank nails to a considerable degree. This taper-threaded nail is still in its experimental stage, although its production methods have been worked out with a minimal increase in manufacturing cost.

Threaded-shank nails may be provided with a clearance, that is, a plain unthreaded section of the nail shank between head and threads. Since no benefit can be derived from threads embedded in the piece of material to be fastened, the length of the clearance may be of the thickness of that member; or a little longer in order to provide a full nail-shank section where maximum stresses may exist during use.

A threaded-shank nail with proper clearance will hold the member to be fastened more tightly than the same nail with no clearance. This is particularly the case for the long-lead helically-threaded nail. If no threads engage the wood fibers of the piece to be fastened, the nail can freely rotate into the wood to which the piece is fastened and, thus, pull the two pieces more tightly together. Hence, for example, the unthreaded portion near the head of a long-lead helically threaded nail can turn freely in a hardwood flooring strip, while the rest of the nail shank threads itself into the softwood sub-flooring. Thus, final driving of the threaded-shank nail with proper clearance can pull top- and sub-flooring more tightly together than is possible with a nail threaded throughout its shank length.

Nail Manufacture

Plain-shank nails are manufactured from smooth round wire, headed and cut on nail machines on a continuous production basis. Thread-rolling, a separate second manufacturing step, involved the cold working of these plain shanks when rolled between dies bearing the proper impressions to form the desired threads.

Nails having long-lead grooves on the shanks can be made from smooth round wire, drawing it to a square or other multi-sided shape, and then twisting the wire before it is cut into nails. Such a manufacturing procedure results, of necessity, in a twisted and grooved nail shank all the way from nail head to nail point, and excludes the desirable clearance beneath the head. Furthermore, the twisted nail cannot be made with a plain-shank portion above the nail point, often required as a pilot.

Hardening (comprising heating, oil-quenching, and tempering), bluelng, hot- and electro-galvanizing, electro-plating, phosphate-dipping, cement-coating, bake-enamelling, etching, and "barbing" are secondary manufacturing steps to provide the nail with properties that satisfy specific requirements.[25] Mass-production procedures must be employed for the above purposes in order that the nails may be sold in a broad market. In this respect, the recent introduction of semi-automatic heating and tempering facilities for nail treatment proves to be a considerable advantage in the effort to satisfy the demand for hardened nails, such as helically-threaded flooring nails, fluted concrete and masonry nails, and for nails which must be driven through steel plate and other hard materials.

Nail Performance

The principal mechanical properties of nails of interest to the nail user are driving resistance, withdrawal resistance, and lateral load-carrying

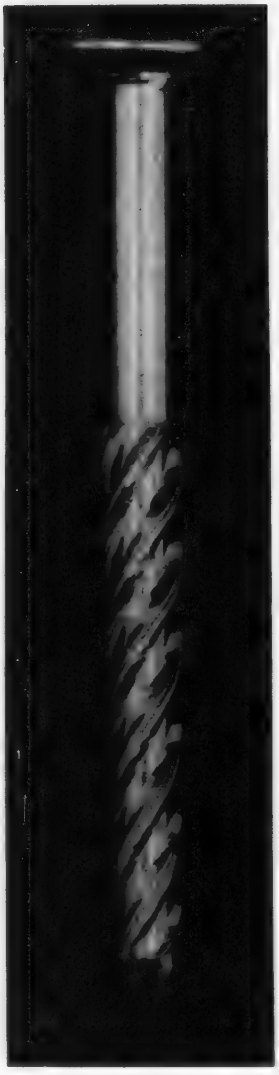


Fig. 2—Experimental 1⅜" x 0.091" helically threaded *Taper Screwtite* nail, five times actual size.

capacity. Creep properties are of major importance for specific fastening purposes.[20,28] Wood-splitting characteristics of nails often govern their selection.

Of considerable influence on the holding power of nails are many factors such as whether the nails are driven into green or air-dry wood, whether the nails are loaded immediately after driving or after some delay, and whether, if the test is a delayed test, there have been changes in the moisture content of the wood. These variable factors greatly affect and decrease the efficiency of plain-shank nails but are much less detrimental to the holding power of threaded-shank nails.[9]

The efficiency in nail-holding power is influenced to a considerable degree by the difference between driving into side-grain or into end-grain lumber.[1,11] If driven parallel to grain into soft wood, the withdrawal resistance of plain-shank nails is, according to the *Wood Handbook*,[1] 50 to 75 percent of that obtained if the nail is driven perpendicular to the grain. On the other hand, in very dense hardwoods, the resistance to withdrawal of plain-shank nails is affected little by the angle at which the nail is driven.

The ratio of axial withdrawal resistance in side-grain southern pine to that in end-grain southern pine of 20 and 10 percent moisture content, respectively, was found to be 1.1 to 1 for plain-shank nails; for the helically threaded nails tested, it was 1.2 to 1 and for the annularly threaded nails tested it was 1.9 to 1. Although the threaded nails showed a larger percentage difference in withdrawal resistance in the end-grain wood, the actual withdrawal resistance was, at all times, considerably greater than that of the plain-shank nails. Thus, in side-grain pine, the withdrawal resistances of the plain-shank, the helically threaded, and the annularly threaded nails were in the ratio of 1 to 1.4 to 2.6; while in the end-grain pine, the ratio was 1 to 1.3 to 1.6, — in all cases, a sizable margin in favor of the threaded-shank nails.

Data on the driving and holding properties of nails for specific uses are presented to further illustrate the advantage of use of threaded-shank nails with respect to holding power. It may be noted that these data are directly attributable only to the types of nails tested because of the variations is design of nails made by different manufacturers. Thus, all data presented on threaded-shank nails are only applicable to helically threaded *Screwtite* nails, annularly threaded *Stronghold* nails, and *Stronghold Screwnails* with a small helix angle, as manufactured by the *Independent Nail & Packing Company of Bridgewater, Massachusetts.*

Comparative test data on driving resistance, immediate and delayed withdrawal resistance and lateral load-carrying capacity are presented in Tables I and II for plain-shank, helically threaded and annularly threaded general-purpose nails in side-grain green and air-dry white oak and beech, and partially air-dry and air-dry southern pine. Nail brittleness, resulting from the heat-treating procedures employed at the time of manufacture of the nails used for these particular tests in 1949, was the cause for the large number of nail-shank failures and relatively low test values observed. The improved heat-treating procedures now used result in greater load-carrying capacity, especially when the nail is stressed in bending and shear. Also, the above test data were obtained before certain improvements in thread design were introduced. Since such improvements resulted in 10 percent average increases in holding power for the helically threaded nails and 6 percent average increases in holding power for the annularly threaded nails.[10] additional increases in holding power can justifiably be expected for threaded-shank nails of present manufacture.

A typical comparison is made in Table III of the effectiveness of 2-½" x 0.135" low-carbon-steel plain-shank and threaded-shank general-purpose nails driven into side-grain air-dry southern pine, white oak, and beech.

A similar comparison is made in Table IV for ⅞" or 1" x 0.120" bright-steel, galvanized-steel, and aluminum-alloy plain-shank and threaded-shank asphalt-roofing, shingle, and siding nails in southern pine.

A further comparison is presented in Table V for 1-¾" x 0.083" or 0.098" bright-finished, electro-plated or hot-dipped galvanized, low-carbon-steel; aluminum-alloy, and bronze, plain-shank and threaded-shank, wood shingle, shake, and siding nails in southern pine.

Table VI gives comparative data on nail-holding power of 1-⅛" or 1-¼" x 0.091" plain-finished and blued low-carbon-steel plain-shank and threaded-shank gypsum-lath nails in southern pine.

Similar comparative data on 1-⅜" x 0.091" plain-finished, metallic-finished, and bonderized aluminum-alloy plain-shank and threaded-shank gypsum-wallboard nails are presented in Table VII.

Additional comparative resistances to axial withdrawal of 2-½" x 0.113" plain-shank flooring brads, 2-½" x 0.115" flat cut flooring nails tapering from a maximum width of 0.321 in. to 0.088 in., and 2-½" x 0.113" helically threaded flooring nails are indicated in Table VIII.

To facilitate a comparison of nail-holding power in the somewhat lighter white fir,[34] axial-withdrawal resistances are given in Table IX for some of the above nails in air-dry white fir of an oven-dry specific gravity of 0.37. A direct comparison of the corresponding data for nails in representative air-dry southern pine and the above air-dry white fir is made in Table X.

Most of the above comparative test data on nail-holding power were obtained for cylindrical plain-shank and threaded-shank nails, with their outermost diameter constant along the shank. The recent introduction of the tapered threaded-shank design results in additional increases in both axial-withdrawal resistance and lateral load-carrying capacity of those threaded nails which are provided with a properly tapered threaded-shank section. Data on these nails for the various applications referred to above have not been obtained to-date; however, they should reveal significant improvements in nail efficiency.

This improvement can be visualized also by studying the dimensional instability of wood over a period of time. During shrinkage and swelling of wood into which the nail is driven, the wood shrinks or swells in both directions from the mid-point of the embedded shank of the plain-shank nail. Similarly, during change in temperature of the nail, it changes its length in both directions from the mid-point of the nail hole in which the plain-shank nail is embedded. On the other hand, the threaded shank nail may have its neutral, that is, stationary center approximately 25 percent of the length of the embedded shank nearer the plank surface than the plain-shank nail.[20,38] A further shift of the neutral center of the embedded nail shank to the plank surface can be expected for the tapered threaded-shank nail, since its holding power per unit of shank length increases with increase in thread-crest diameter. Thus, nail creep, resulting from small periodic or cyclic changes in atmospheric conditions, specifically from changes in humidity and temperature and the resulting unequal dimensional changes in nail shank and wood, is considerably smaller for threaded-shank nails than for plain-shank nails and should be further decreased by properly tapering the threaded-shank nail. Such decreases in nail creep can be of considerable importance wherever a creeping nail results in decrease in joint effectiveness, loose joints, marred joint appearance, and leakage, and wherever the joint efficiency is otherwise detrimentally effected by nail creep.

Cumulative outward nail creep, resulting from cumulative increases in outward creep and decreases in inward creep during consecutive repetitive exposure,[38] is the reason for periodic and cyclic increases in amount of backing-out or popping of nails. Because of the fact that the wood fibers cantilever into the threads of threaded-shank nails and offer resistance to slipping of the thread crests over these wood fibers, popping of threaded-shank nails is seldom observed.

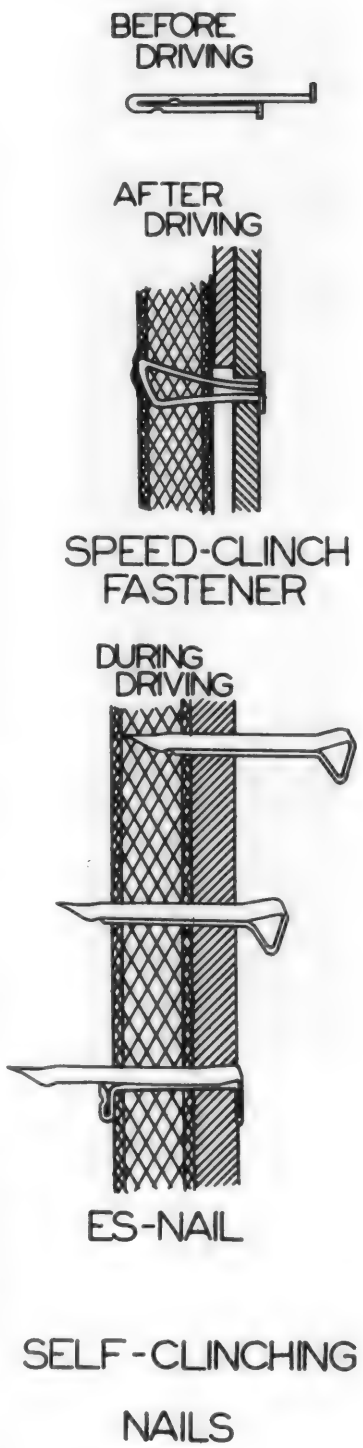
Splitting of wood by nails can be eliminated by choosing the proper nail-shank diameter and point, by retaining a sufficient distance between end of plank and nail, and by pre-drilling as a last resort. The comparatively large holding power of threaded-shank nails often allows use of a threaded-shank nail with smaller shank diameter than that of the plain-shank nail providing same holding power, particularly if a hardened nail is used. Thus, splitting of wood can often be prevented by choosing the most satisfactory nail. Fully comparative data on non-splitting properties of nails for different wood species and plank thicknesses at common moisture contents are not available. A detailed basic study of the factors involved is justified.

Clinching and Self-Clinching Nails

While the previously described nails rely on frictional or a combination of frictional and shear forces for their holding power, they may also be clinched, that is, their points may be bent over to increase their efficiency even further.[12] Thus, clinching of 2″ x 0.135″ low-carbon steel-wire nails increased their withdrawal resistance immediately after driving through side-grain air-dry southern pine 65 percent if of the plain-finished plain-shank type, 45 percent if of the cement-coated plain-shank type, 100 percent if of the helically threaded type, and 35 percent if of the annularly threaded type. Since the non-clinched threaded-shank nails can provide considerably larger holding power than the plain-finished or cement-coated clinched plain-shank nails, clinching of plain-shank nails does not appear justified if threaded-shank nails are available.

Screw Design

If a nail is properly defined as "a slender, usually pointed and headed fastener designed for hammer- or machine-driving," a wood screw is "a relatively heavy-gauged, pointed and headed fastener designed to be



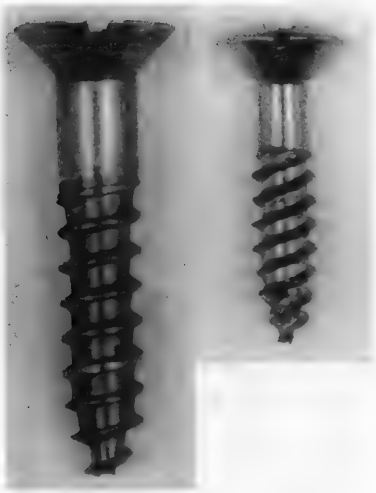


Fig. 3—Left, No. 16—1½" x 0.267" standard wood screw, 2½ times actual size. Note, maximum crest diameter is that of shank along clearance; eccentric point. Right, 1" x 0.215" *Twinfast* wood screw with slotted and oval head, 2½ times actual size. Note, parallel twin threads; relieved shank diameter along clearance; concentric point.

turned by a screwdriver." In its simplest standard form, the wood screw has a continuous helical short-lead thread around a slightly tapered shank from which it projects. The thread-crest diameter is that of the plain-shank section between head and threads, with the thread-root diameter being relieved (Fig. 3).

A basic improvement for wood screws is the use of parallel twin threads which allow faster turning into wood without decreasing holding power. Increase in thread-crest diameter beyond that of the plain-shank section between head and threads, in other words, relieved shank diameter between head and threads can be considered another important improvement in the design of wood screws, since such wood screws offer increased holding power. If manufactured with a single centered point, by extending the thread to the tip of the point, the wood screw is more likely to turn straight into wood than otherwise. Thus, the design refinements for wood screws result in a better product, allow faster driving, tighter fastening, and fewer rejections.

Screw Performance

The aim of wood screws is the same as that of nails, that is, to fasten materials together with maximum holding efficiency. The holding properties of common standard wood screws in the commonly-used wood species have been extensively investigated.[39-46] On the other hand, holding properties of such improved wood screws as the recently introducted twin-threaded wood screws (Fig. 3, right) in commonly used wood species are not yet available.

Nail Performance vs. Screw Performance

A limited number of fully comparative test data was recently obtained[41] on the efficiency in holding power of plain-shank and threaded-shank nails and standard wood screws, as shown in Fig. 4.

Matched quintuplicate tests were performed on

(1) 2-½, 3, and 4-in. long, 0.135, 0.148, and 0.203-in. wire-diameter, low-carbon-steel, plain-finished and etched plain-shank, plain-finished helically threaded, and plain-finished annularly threaded nails with diamond points and ⅞, 1, and 1-⅛-in. clearances, respectively, between flat heads and rolled-on shapes. The helically threaded nails were provided with a 60-deg. thread slope and the annularly threaded nails with a 0.060-in. center-to-center thread spacing.

(2) Nos. 5, 6, 7, and 8, that is, ¾, 1, 1-½, and 2-in. long, 0.125, 0.138, 0.151, and 0.164-in. wire-diameter, low-carbon-steel flat-head wood screws with 5 32, 3 16, 7 16, and 9 16-in. clearances, respectively, between slotted heads and threads, as shown in Fig. 4.

The nails were hammer-driven and the screws were turned to two-third shank penetration into southern (shortleaf) pine and white oak, having a moisture content of 10 - 11 percent, and into beech, having a moisture content of 18 - 24 percent. The average oven-dry specific gravities of the test planks were 0.52 - 0.56, 0.70, and 0.63 - 0.74, respectively, for the above wood species. The wood screws were screwed into pre-bored holes of 1 16-in. diameter for Nos. 5, 6, and 7 screws in pine, of 5 64-in. diameter for No. 8 screw in pine and Nos. 5 and 6 screws in oak and beech, and of 3 32-in. diameter for Nos. 7 and 8 screws in oak and beech. The tests were performed for axial-withdrawal resistance and lateral load-carrying capacity immediately after driving according to previously established standards.[7-12]

Fig. 4—From left to right, No. 8—2" x 0.164", No. 7 — 1½" x 0.151", No. 6—1" x 0.138", and No. 5 — ¾" x 0.125" standard wood screws after axial withdrawal from southern pine, twice actual size.

The average test data are presented in Table X1. The average axial-withdrawal resistances per inch of shank penetration are plotted in Fig. 5.

According to the information presented, wood screws of same wire diameter, however, with a 64 percent smaller shank penetration than plain-shank nails provide, on the average, a 16 percent smaller axial-withdrawal resistance and a 53 percent smaller lateral load-carrying capacity; however, they provide a 124 percent greater axial-withdrawal resistance per inch of shank penetration in the three wood species investigated. In comparison with the annularly threaded nails, the above wood screws provide, on the average, a 46 percent smaller axial-withdrawal resistance and a 60 percent smaller lateral load-carrying capacity for the respective two-third shank penetrations; however, they provide a 43 percent greater axial-withdrawal resistance per inch of penetration.

Fully comparative supplementary quintuplicate tests were performed on the axial-withdrawal resistance of the above No. 6 wood screw and 2-½" x 0.135" low-carbon-steel plain-finished plain-shank nails and cylindrical and tapered threaded nails shown in Fig. 6. These fasteners were embedded to two-third shank penetration in Douglas fir of an oven-dry specific gravity of

0.51 and a moisture content of 10 percent. The above wood screw, with a 2 percent larger shank diameter and a 60 percent smaller shank penetration, provided a 54 percent larger axial-withdrawal resistance than the above plain-shank nail and a 50 and 48 percent, respectively, smaller axial-withdrawal resistance than the cylindrical and tapered threaded *Stronghold Screwnails*. Hence, the axial-withdrawal resistance per inch of penetration of the wood screw was 235, 26, and 18 percent, respectively, larger than those of the plain-shank nail and the cylindrical and tapered threaded-shank *Stronghold Screwnails*.

While the wood screws of similar shank diameter, however, smaller shank penetration than the tested nails offered a smaller resistance to axial withdrawal, they offered a greater resistance per inch of shank penetration than the threaded-shank nails. Thus, the axial-withdrawal resistance per inch of penetration of the wood screw was, on the average, 43 percent greater than that of the *Stronghold nail* in southern pine, white oak, and beech; and 26 percent greater than that of the *Stronghold Screwnail* and 18 percent greater than that of the *Taper Stronghold Screwnail* in Douglas fir.

Hence, threaded-shank nails can be considerably more efficient with respect to holding power than shorter wood screws of same wire diameter. On the other hand, wood screws offer greater holding power per inch of penetration than any of the tested nails.

The gap between the efficiency of wood screws and nails, however, has been narrowed considerably with improvements in design of threaded-shank nails. Thus, the withdrawal resistance per inch of shank penetration of the *Taper Stronghold Screwnail* tested was only 18 percent smaller than that of the wood screw made of wire of 2 percent larger diameter. Further investigations as to optimum taper and improvements in thread design may make it possible to approximate even more nearly the holding power of wood screws.

Since, according to previously discussed data, clinching may increase the axial-withdrawal resistance of the anularly threaded nails in southern pine as much as 35 percent, it can be assumed that a similar increase in holding power per inch of penetration of the clinched *Stronghold Screwnail* would surpass the holding power per inch of penetration of wood screws of same diameter. Directly comparative test data, however, have not been obtained to-date.

ECONOMIC ASPECTS

Manufacturing Cost of Threaded-Shank Nails and Wood Screws

A cost comparison of plain-shank and threaded-shank nails must take into account that threading is a second manufacturing step in nail production, which increases the cost of the threaded-shank nails in comparison with that of the plain-shank nails. On the other hand, this increased cost, on the average, amounting to 60 percent over the cost of the plain-shank nails used in building construction, [8,13] can result in considerable product

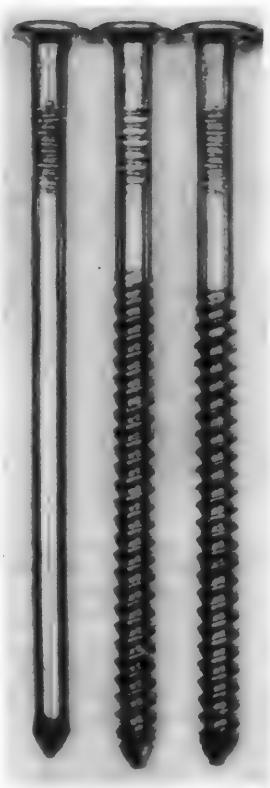


Fig. 6—From left to right, tested 2½" x 0.135" plain-shank nail, *Stronghold Screwnail*, and *Taper Stronghold Screwnail*, twice actual size.

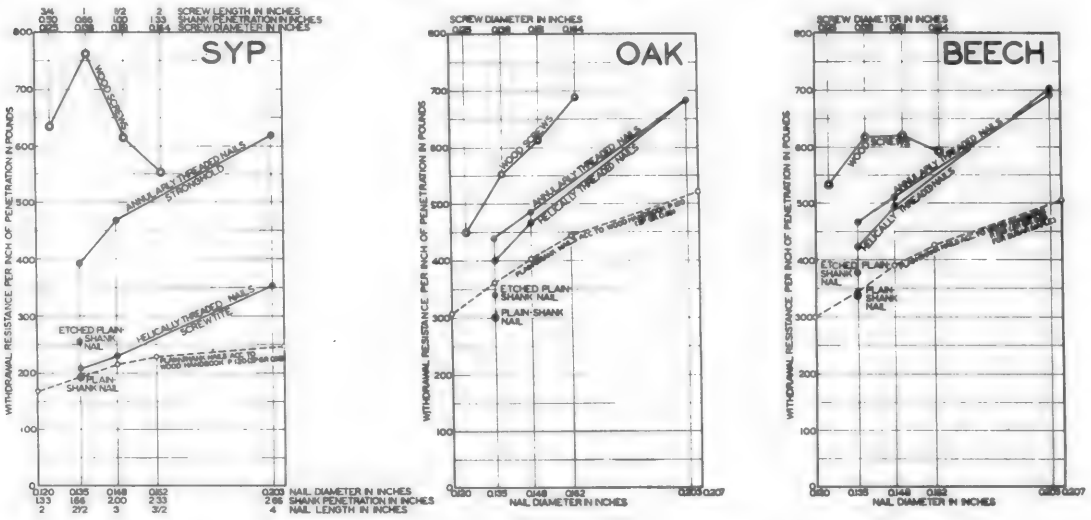


Fig. 5—Axial withdrawal resistance of nails and wood screws in 3 species.

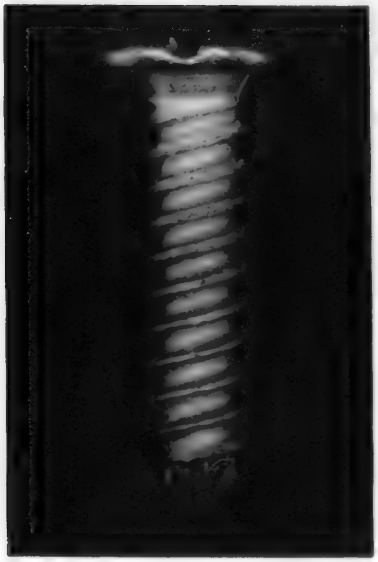


Fig. 7—Electro-plated $\frac{5}{8}$" x 0.120" *Stronghold Screwnail* with slotted and oval head, replacing wood screw for fastening Venitian blinds, five times actual size.

improvement and, in some cases, can cut total costs. In many cases, it is possible to decrease the number of nails used because of the increased holding power of threaded-shank nails in comparison with that of plain-shank nails. Under such conditions, the actual cost difference for threaded-shank nails used is less than that given above.

In the case of flooring and stair-tread nails, the helically threaded nails can replace twice as many cut flooring nails on a weight basis alone, without regarding the better performance of the threaded nails. Such replacement results in an actual purchase-cost saving of 28 percent, while the laid floor and staircase is of superior quality.[8,13,16]

A comparison of the present cost of threaded-shank nails and wood screws to the jobber provides a means of examining the direct economy involved in the purchase of threaded-shank nails and wood screws for wood assembly and construction. Thus, e. g., a $\frac{7}{8}$" x 0.120" threaded-shank nail with 323 nails per pound, costs $19.25 per 100 pounds or $0.596 per 1,000 nails. A same-size wood screw costs $2.18 per 1,000 screws. Hence, the cost ratio to the jobber of threaded-shank nails to same size wood screws is 1 to 3.66. In other words, the wood screw is 3-$\frac{2}{3}$ times more expensive than the threaded-shank nail.

A possibly more valuable comparison is made by presenting data on the holding power of threaded-shank nails and wood screws in pounds per dollar. Using the above cost data and the presented ratio of axial-withdrawal resistance per inch of penetration of *Stronghold Screwnails* and wood screws of similar wire size of 1 to 1.26, the ratio of holding power in pounds per dollar of the above nail and screw amounts to 1 to 2.90. Hence, the cost of the wood screw with respect to holding power is almost three times that of the threaded-shank nail.

The above ratios vary, of course, with the efficiencies of nails and screws of different sizes in different wood species under different use condictions, thus, must be weighed in light of the presented date.

Information on the comparative cost of threaded-shank nails in actual replacement of wood screws may be of interest. Thus, e. g., a manufacturer of Venetian blinds recently purchased two million *Stronghold Screwnails*, as shown in Fig. 7, for 60 percent of the cost of wood screws previously used by him.

Application Efficiency of Threaded-Shank Nails and Wood Screws

On the average, approximately 15 to 20 percent more energy is required to drive threaded-shank nails than plain-shank nails. This small increase in driving resistance is, however, accompanied by 12 to 760 percent increased axial-withdrawal resistance and 3 to 100 percent increased lateral load-carrying capacity according to the test data presented in Tables I and II. Considering the product improvement and the possibility that a smaller number of smaller-size threaded-shank nails than plain-shank nails may be needed to fulfill the fastening requirements, the small increase in required energy for driving threaded-shank nails is insignificant. If the nails are machine-driven, as is the case under mass-production procedures, the increased energy requirements are negligible.

Similarly clinching of nail points results in increased production cost which may not be justified when unclinched threaded-shank nails can perform a better service than clinched plain-shank nails. Clinching may not only increase the cost of labor, it also increases the cost of the nail because of the required increase in nail length for clinching purposes. Furthermore, clinching may be undesirable because the exposed parts of the nail may be the cause of complaints and may result in unsightly appearance. On the other hand, clinching of threaded nails may be fully justified when holding-power requirements call for such increase in withdrawal resistance as can be provided by clinching threaded-shank nails.

While nails are hand- or machine-hammered into wood, wood screws may be hammered only initially and finally must be turned into wood with either a hand- or machine-screwdriver. In the case of either hand or machine operation, the time required for hammering is considerably shorter than that for screwing.

Pre-drilling of a pilot hole for nails is the exception rather than the rule and often may be avoided even for hardwood assembly by using heat-treated high-carbon-steel nails. On the other hand, pre-drilling of a pilot hole for the insertion of wood screws is usually taken for granted for reasons of production efficiency and because of the danger of twisting the screw shank if the screw is turned into wood by excessive force.

The time and cost involved in drilling pilot holes for wood screws must, of course, also be given consideration when determining the final cost of threaded-shank nails versus that of wood screws. Thus, it has been possible for some boat builders to reduce their labor cost alone 25 percent by

replacing wood screws with annularly threaded *Anchorfast* nails, the Monel equivalent of the annularly threaded nails, for fastening hull planking.

Product Improvement by Replacement of Plain-Shank Nails with Threaded-Shank Nails

While a smaller number of smaller-size threaded-shank nails may provide the same holding power as that of plain-shank nails previously used, the benefit of threaded-shank nails becomes most outstanding wherever plain-shank nails provide insufficient holding power and properly threaded nails offer the answer to the fastening problem.

Gold miners in California report that sluice boxes, water troughs, and concentrate tables while leaking lost over 12-½ percent of the gold through cracks when the wooden assemblies were built with plain-shank nails. On the other hand, these wooden containers have remained in satisfactory and tight condition whenever assembled with threaded-shank nails.

While fruit-picking lugs have had a normal service life of 7 to 8 years if assembled with plain-shank nails, the use of threaded-shank nails has extended their life 2 to 3 years longer.

Bottle cases, lobster pots, wooden flumes, chicken coops, collapsible chicken crates, feeding trays, hog pens, brooder houses, mushroom flats, seed flats, cold frames, greenhouse benches, pickling vats, water tanks, cooling towers, tobacco barns, boats, industrial trucks, truck bodies, and freight cars have provided longer and more satisfactory service if assembled with properly threaded nails than with plain-shank nails or wood screws, since the latter fastenings may back out as a result of creep or because of prevailing vibration. Culverts, bridges, wharves, docks, piers, and boardwalks exposed to continuous and extreme changes in moisture content of their wood are apt to fail as a result of excessive popping of nails if properly threaded nails are not used for their assembly. Bridge planking had to be re-nailed every six months to eliminate the danger resulting from popped plain-shank nails, until threaded-shank nails provided the required service. Such damage resulting from popped plain-shank nails is particularly impairing if road planking at railroad grade crossings is fastened to railroad ties with plain-shank nails, since the popped nails play havoc with automobile tires. This planking must be fastened flexibly to allow tie movement and on a temporary basis to make possible economical periodical tie replacement. Threaded nails, spikes, and drift bolts provide such flexible and temporary means of fastening for this road planking.

Bump tests on boxes revealed that identical boxes assembled with cement-coated plain-shank nails withstood 8 bumps, if assembled with the helically threaded nails withstood 24 bumps, and if assembled with the annularly threaded nails withstood 30 bumps before failure was observed.

Use of wooden pallets would be uneconomical if they were not assembled with threaded-shank nails. On the other hand, because of the construction features made possible by the availability of threaded-shank nails, they are in such common use that they are mass-assembled with *Stronghold Screwnails* at a rate of one a minute by a single pallet manufacturer among many.

In the construction of bowling alleys, use of threaded-shank nails is a must to ascertain permanently tight flooring. Fully satisfactory use of hickory for flooring purposes would be "unthinkable" without laying it with heat-treated threaded flooring nails. Fastening underlay for linoleum with plain-shank nails may result in their showing through the linoleum several months after laying because of nail creep, while threaded-shank nails remain tight in the sub-flooring, thus do not mar the linoleum.

In the assmebly of case goods, especially of unbalanced construction, the large holding power of threaded-shank nails may result in a tight joint which previously never could be fully accomplished under extreme exposure conditions in adverse surroundings during service.

Unsheathed house frames were found to be 4.6 to 5.7 times as strong if assembled with the annularly threaded nails than identical frames assembled with same size plain-shank nails.[14] Weak wood species may be up-graded by using threaded-shank nails,[34] since the assemblies generally are only as strong as their joints and since properly threaded-shank nails considerably improve joint strength.

Decrease in Assembly Cost by Replacement Of Screws with Threaded-Shank Nails

While the product may be improved by replacement of plain-shank nails with threaded-shank nails, the product may be manufactured more economically without decreasing, and even sometimes increasing, its quality by replacing wood screws with threaded-shank nails.

The world's fastest boat, nailed together with *Anchorfast* nails, ran as fast as 160 miles per hour without even showing any cracks of her varnish

at the planking joints. Such a feat was accomplished with a boat assembled with a labor saving of 25 percent by replacing wood screws with threaded-shank nails.

Assembly of toys, wooden ware for bakers and confectioners, typewriter cases, office and typewriter desks, folding tables, upholstery frames, day beds, novelty furniture, baby carriages, boxes, crates, and other containers; fastening of broom and shovel handles, metallic bindings, Venetian blinds and awnings, trim and mouldings, car linings, and window and door sash with threaded-shank nails instead of wood screws "has cut production cost tremendously" and, in many cases, increased their useful life.

Use of fluted masonry and concrete nails has made possible the elimination of both pre-drilling and the use of machine screws in expansion shields. The economy involved in fastening conduits and pipe hangers to walls and ceilings with such fluted-shank nails is far reaching whenever the use of these nails becomes more prevalent than is the case today.

OUTLOOK

Considerable progress has been made in the design and manufacture of nails and wood screws. Important knowledge has been obtained with respect to their efficiency. The use of threaded-shank nails has increased to such a degree that manufacturing capacity for these nails had to be increased to several times of that available before and during World War II. The demand for these improved nails, however, calls for further increase in their production.

On the other hand, relatively little is known about these improved fasteners. The investigations made to-date could only cover the immediate aspects and problems in this field of fastening. Such propositions, as the use of a small taper along the threaded shank, result in new possibilities which may solve many fastening problems, hitherto not solved or not solved economically.

While few studies on nails and screws in wood assembly and construction were made a few years ago, numerous investigations are underway on behalf of nail and screw manufacturers and wood users at this time. The continuity of such investigation is ascertained thanks to the foresight of the Independent Nail & Packing Company of Bridgewater, Massachusetts, a pioneer in this field of endeavor and sponsor of such investigations which have resulted in most of the presented data.

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APPENDIX Tables I–XI

Table I
Grand Averages for Matched Duncple Tests
On Driving Resistance, Withdrawal Resistance, and Lateral Load-Carrying Capacity
For Plain-Shank, Helically Threaded, and Annularly Threaded Nails
In Green White Oak, Green Beech, and Partially Air-Dry Southern Yellow Pine

ll ge K Dia. inches)	Nail Type	Wood Species	Driving Resistance Shank Penetration (In Inches)			Withdrawal Resistance For 2/3 Shank Penetration (In Pounds)			Lat. Load-Carrying Cap. For 2/3 Shank Penetration (In Pounds)		
			Plain	Helically Threaded	Annularly Threaded	Plain	Helically Threaded	Annularly Threaded	Plain	Helically Threaded	Annularly Threaded
0.120"	HC-HH-HC-D	Oak	1.04	—	—	313	—	—	604	—	—
		Beech	0.88	—	—	314	—	—	355	—	—
		SYP	1.08	—	—	295	—	—	406	—	—
	HC-H-HC-D	Oak	1.10	0.92	0.95	394	542	530	544	696	695
		Beech	0.87	0.70	0.75	419	494	426	370	342	347
		SYP	1.18	1.02	1.06	335	500	525	491	571	636
	HC-HH-HC-V	Oak	0.95	—	—	289	—	—	387	—	—
		Beech	1.06	—	—	140	—	—	361	—	—
		SYP	—	0.86	0.93	—	560	511	—	688	771
	HC-H-HC-V	SYP	—	0.91	1.05	—	655	478	—	612	280
0.120"	HC-HH-HC-D	Oak	1.01	—	—	375	—	—	625	—	—
		Beech	0.84	—	—	168	—	—	511	—	—
		SYP	1.16	—	—	198	—	—	393	—	—
	HC-H-HC-D	Oak	1.06	0.88	0.96	472	658	662	598	497	518
		Beech	0.83	0.68	0.75	520	719	688	445	466	497
		SYP	1.18	1.01	1.02	380	680	619	356	563	435
	HC-HH-HC-V	Oak	0.91	—	—	374	—	—	612	—	—
		Beech	1.01	—	—	181	—	—	357	—	—
		SYP	—	0.91	0.90	—	652	662	—	708	391
	HC-H-HC-D	Oak	—	0.73	0.71	—	711	688	—	561	328
		Beech	—	1.13	1.08	—	630	526	—	756	403
	HC-H-HC-V	Oak	—	0.87	0.90	—	657	—	—	922	219
		Beech	—	0.92	1.01	—	533	—	—	530	207
	HC-H-HC-D-V	Oak	—	0.89	0.93	—	623	646	—	591	308
		Beech	—	0.69	0.72	—	674	444	—	597	294
		SYP	—	0.99	1.09	—	535	607	—	745	275
0.135"	LC-HH-HC-D	Oak	0.93	0.73	0.72	401	645	732	700	799	597
		Beech	0.77	0.62	0.60	462	627	706	355	483	638
		SYP	1.08	0.86	0.88	264	331	444	500	751	630
	LC-H-HC-D	Oak	0.95	—	—	515	—	—	798	—	—
		Beech	0.76	—	—	492	—	—	421	—	—
		SYP	1.12	—	—	438	—	—	638	—	—
0.135"	HC-HH-HC-D	Oak	0.85	—	—	408	—	—	773	—	—
		Beech	0.49	—	—	502	—	—	577	—	—
		SYP	1.08	—	—	243	—	—	467	—	—
	HC-H-HC-D	Oak	0.89	0.73	0.75	639	859	785	1170	1373	758
		Beech	0.53	0.35	0.40	702	841	851	685	681	742
		SYP	1.08	0.91	0.97	588	728	736	926	1252	782
0.148"	LC-HH-HC-D	Oak	0.75	0.63	0.60	541	688	866	906	1071	1080
		Beech	0.69	0.54	0.54	623	737	888	676	820	769
		SYP	0.90	0.75	0.75	366	362	825	567	830	1059
0.162"	LC-HH-HC-D	Oak	0.68	0.56	0.56	663	929	1072	1081	1178	1235
		Beech	0.61	0.47	0.47	795	966	959	630	881	925
		SYP	0.80	0.67	0.66	629	609	1015	678	936	1198
0.177"	HC-HH-HC-D	Oak	0.62	—	—	834	—	—	1241	—	—
		Beech	0.50	—	—	1061	—	—	1224	—	—
		SYP	0.79	—	—	491	—	—	914	—	—
	HC-H-HC-D	Oak	0.64	0.48	0.55	1100	1111	1397	2284	2559	1903
		Beech	0.49	0.40	0.45	1232	1291	1273	1465	1522	1513
		SYP	0.74	0.53	0.61	792	1112	1100	1465	1939	1353
0.207"	LC-HH-HC-D	Oak	0.54	0.47	0.46	815	1093	1187	1243	1949	2031
		Beech	0.44	0.38	0.34	1093	1159	1256	1235	1975	1890
		SYP	0.64	0.54	0.53	403	664	1170	949	1545	1550

LC = Low-Carbon Steel
HC = High-Carbon Steel
H = Non-Hardened
H = Hardened
HC = Non-Coated
CH = Cement-Coated
D = Diamond Point
V = V Point
F = Filet

Table II

Grand Averages for Matched Decuple Tests on Driving Resistance and Delayed Withdrawal Resistance And for Sextuple Tests on Delayed Lateral Load-Carrying Capacity Of Plain-Shank, Helically Threaded, and Annularly Threaded Nails In Air-Dry White Oak, Beech, and Southern Yellow Pine With Nails for Tests on Withdrawal Resistance and Lateral Load-Carrying Capacity Driven into Green White Oak, Green Beech, and Partially Air-Dry Southern Yellow Pine

Nail Size Length x Wire Dia. (In Inches)	Nail Type	Wood Species	Driving Resistance Shank Penetration (In Inches)			Withdrawal Resistance For 2/3 Shank Penetration (In Pounds)			Lat. Load-Carrying Cap. For 2/3 Shank Penetration (In Pounds)		
			Plain	Helically Threaded	Annularly Threaded	Plain	Helically Threaded	Annularly Threaded	Plain	Helically Threaded	Annularly Threaded
2" x 0.120"	MC-MH-MC-D	Oak	0.78	——	——	373	——	——	494	——	——
		Beech	——	——	——	173	——	——	542	——	——
		SYP	0.97	——	——	37	——	——	334	——	——
	MC-H-MC-D	Oak	0.85	0.73	0.76	394	718	716	466	599	510
		Beech	——	——	——	278	616	490	499•	586•	448•
		SYP	1.03	0.91	0.93	91	457	360	473•	637•	292•
	MC-MH-MC-V	Oak	0.73	——	——	413	——	——	605	——	——
		SYP	0.93	——	——	34	——	——	366	——	——
	MC-H-MC-V	Oak	——	0.68	0.75	——	742	668	——	659•	359•
		SYP	——	0.82	0.86	——	440	380	——	690	325•
2½" x 0.120"	MC-MH-MC-D	Oak	0.78	——	——	451	——	——	615	——	——
		Beech	——	——	——	172	——	——	557•	——	——
		SYP	0.96	——	——	50	——	——	327	——	——
	MC-H-MC-D	Oak	0.88	0.71	0.76	410	835	712	470•	522•	393•
		Beech	——	——	——	234	816	525	434•	937•	409•
		SYP	0.99	0.84	0.93	110	611	386•	432•	635•	313•
	MC-MH-MC-V	Oak	0.68	——	——	546	——	——	646	——	——
		SYP	0.87	——	——	38	——	——	320	——	——
	MC-H-CC-D	Oak	——	0.76	0.77	——	753	855	——	784	508•
		Beech	——	——	——	——	827	713	——	1019	536•
		SYP	——	0.92	0.93	——	701	508	——	726•	373•
	MC-H-MC-V	Oak	——	0.68	0.70	——	854	695	——	739•	101•
		SYP	——	0.81	0.83	——	523	416	——	712•	243•
	MC-H-MC-D-P	Oak	——	0.70	0.72	——	770	701	——	681•	459•
		Beech	——	——	——	——	769	502•	——	920	323•
		SYP	——	0.84	0.91	——	377	417	——	509•	338•
2½" x 0.135"	LC-MH-MC-D	Oak	0.70	0.59	0.59	383	872	940	640	856	732
		Beech	0.47	0.39	0.41	227	750	585	692	1056•	877•
		SYP	0.89	0.74	0.74	77	223	524	415	731	580
	LC-MH-CC-D	Oak	0.76	——	——	455	——	——	637	——	——
		Beech	0.53	——	——	190	——	——	596	——	——
		SYP	0.95	——	——	241	——	——	507	——	——
3" x 0.135"	MC-MH-MC-D	Oak	0.63	——	——	385	——	——	633	——	——
		Beech	0.51	——	——	210	——	——	615	——	——
		SYP	0.92	——	——	68	——	——	331	——	——
	MC-H-MC-D	Oak	0.68	0.57	0.58	440	1020	1054	914	1306	718•
		Beech	0.57	0.49	0.49	435	902	726	1214	1361	901•
		SYP	0.93	0.80	0.85	176	825	538	759	1128	627
3" x 0.148"	LC-MH-MC-D	Oak	0.54	0.47	0.47	648	1043	1110	780	1159	1111
		Beech	0.44	0.38	0.38	257	920	845	793	1086	1004
		SYP	0.80	0.66	0.67	78	224	672	583	721	875
3½" x 0.162"	LC-MH-MC-D	Oak	0.53	0.45	0.44	485	1228	1268	892	1407•	1238
		Beech	0.40	0.36	0.35	306	1072	949	983	1269	1167
		SYP	0.71	0.57	0.56	85	441	776	496	1033	938
4" x 0.177"	MC-MH-MC-D	Oak	0.51	——	——	867•	——	——	1604	——	——
		Beech	0.33	——	——	463	——	——	1277	——	——
		SYP	0.55	——	——	110•	——	——	675	——	——
	MC-H-MC-D	Oak	0.53	0.37	0.42	842•	1593•	1699•	1707	2287	1788•
		Beech	0.34	0.27	0.31	937	1791	1230	1601	1933	1143•
		SYP	0.69	0.44	0.52	190•	1366•	944•	1142	1575	934•
4" x 0.203"	LC-MH-MC-D	Oak	0.41	0.35	0.33	814•	1537•	1577•	1668	2152	1827•
		Beech	0.29	0.27	0.24	361	1392	1176	1184	1637	1471
		SYP	0.48	0.47	0.47	105•	637•	974•	715	1549	1201

LC = Low-Carbon Steel
MC = High-Carbon Steel
MH = Non-Hardened
H = Hardened
MC = Non-Coated
CC = Cement-Coated
D = Diamond Point
V = V Point
P = Pilot

• = Shank Failure in One-Half or More Than One-Half of Tests

• = True Value Possibly Slightly Larger

Table III

Average Effectiveness of 2-1/2" x 0.135" Low-Carbon-Steel Plain-Shank and Threaded-Shank General-Purpose Nails in Side-Grain Southern Pine

Driven When	Tested When	Nail Property In Southern Pine	Plain Shank Nail	Helically Threaded Screwtite Nail	Annularly Threaded Stronghold Nail
			Pounds	Percent	Percent
Partially Air-Dry	Partially Air-Dry	Withdrawal Resistance	264	+ 25	+144
		Lateral Load-Carrying Capacity	500	+ 50	+ 24
Partially Air-Dry	Air-Dry	Delayed Withdrawal Resistance	77	+190*	+591*
		Delayed Lat. Load-Carrying Capacity	415	+ 76	+ 40

*For 2-1/2" x 0.120" helically threaded Screwtite and annularly threaded Stronghold hardened high-carbon-steel nails, these values increase to +1122 percent and +672 percent, respectively, beyond the corresponding value of 50 lb. for the plain-shank non-hardened low-carbon-steel nail.

Table IV

Average Effectiveness of 7/8" or 1" x 0.120" Plain-Shank and Threaded-Shank Asphalt-Roofing, Shingle, and Siding Nails in Side-Grain Air-Dry Southern Pine

Nail Property In Air-Dry Southern Pine	Nail Metal	Nail Length	Plain Shank Nail	Helically Threaded Screwtite Nail	Annularly Threaded Stronghold Nail
		Inches	Pounds	Percent	Percent
Withdrawal Resistance	Bright Steel	7/8	108	+23.1	+45.4
		1	97	+63.9	+69.1
	Galvanized Steel	7/8	127	+15.0	+26.8
		1	112	+27.7	+50.9
	Aluminum Alloy	7/8	100	+27.0	+33.0
		1	102	+36.3	+60.8
	Average			+32.2	+47.7
Lateral Load-Carrying Capacity	Bright Steel	7/8	232	+36.2	+ 6.5
		1	220	+21.4	+17.7
	Galvanized Steel	7/8	224	+10.7	- 3.2
		1	217	+14.3	+ 5.1
	Aluminum Alloy	7/8	198	+29.6	+20.1
		1	209	+29.2	+10.0
	Average			+23.6	+ 9.4

Table V

Average Effectiveness of 1-3/4" x 0.083" or 0.098" Plain-Shank and Threaded-Shank Wood-Shingle, Shake, and Siding Nails in Side-Grain Air-Dry Southern Pine

Nail Property In Air-Dry Southern Pine	Nail Metal	Nail Lgth. In Inches	Nail Finish	Spec. Grav. Of Wood	Plain-Shank Nail	Barbed Nail	Helically Threaded Screwtite Nail	Annularly Threaded Stronghold Nail, Thread Spacing 0.045"	Annularly Threaded Stronghold Nail, Thread Spacing 0.060"	Helically Threaded Stronghold Screwnail, Thread Spacing & Angle 0.045" & 13-4/2°	Helically Threaded Stronghold Screwnail, Thread Spacing & Angle 0.060" & 18°
					Pounds	Percent	Percent	Percent	Percent	Percent	Percent
Withdrawal Resistance	Steel	0.083	Plated	0.45	73	-------	-------	-------	-------	-------	-------
	Steel	0.083	Dipped	0.45	81	-------	-------	• 75	-------	-------	• 69
	Steel	0.098	Bright	0.55	60	-------	• 90	•239	-------	-------	-------
	Alum.	0.098	Bright	0.45	82	-------	-------	•215	-------	-------	•188
	Alum.	0.098	Bright	0.55	87	-------	• 95	•260	-------	-------	-------
	Alum.	0.098	Bright	0.60	132	-9	-------	•121	•111	•127	•133
	Bronze	0.098	Bright	0.55	51	-------	•115	•290	-------	-------	-------
Lateral Load-Carrying Capacity	Steel	0.083	Plated	0.45	188	P	-------	-------	-------	-------	-------
	Steel	0.083	Dipped	0.45	247	-------	-------	• 19	-------	-------	• 13
	Steel	0.098	Bright	0.55	213	-------	• 23	• 21	-------	-------	-------
	Alum.	0.098	Bright	0.45	168	-------	-------	- 14	-------	-------	- 3
	Alum.	0.098	Bright	0.55	161	-------	• 11	• 23	-------	-------	-------
	Alum.	0.098	Bright	0.56	199	-7	-------	- 12	- 6	- 10	- 3
	Alum.	0.098	Bright	0.60	215	-1	-------	• 5	- 16	2 0	• 8
	Bronze	0.098	Bright	0.55	207	-------	• 7	• 19	-------	-------	-------

Table VI

Average Effectiveness of 1-1/8" or 1-1/4" x 0.091" Plain-Shank and Threaded-Shank Gypsum-Lath Nails in Side-Grain Air-Dry Southern Pine

Nail Property In Air-Dry Southern Pine	Driven Into Plank	Plain-Finished Plain-Shank Nail	Plain-Finished Helically Threaded Screwtite Nail	Plain-Finished Helically Threaded Stronghold Screwnail	Blued Helically Threaded Stronghold Screwnail
		Pounds	Percent	Percent	Percent
Withdrawal Resistance	Directly	85	•105	•107	•121
	Through Lath	200	• 34	• 27	• 25
Lateral Load-Carrying Capacity	Directly	248	• 47	• 14	• 22
	Through Lath	298	• 35	• 1	• 7

Table VII

Average Effectiveness of 1-3/8" x 0.091" Plain-Shank and Threaded-Shank Gypsum-Wallboard Nails in Side-Grain Air-Dry Southern Pine

Nail Property In Air-Dry Southern Pine	Driven Into Plank	Nail Shank Penetration	Annularly Threaded Stronghold: Plain-Shank Plain-Finished Nail	Annularly Threaded Stronghold: Plain-Finished Nail	Annularly Threaded Stronghold: Metallic Finished Nail	Annularly Threaded Stronghold: Bonderized Nail	Helically Threaded Stronghold Screwnail: Thread Spacing 0.029"	Helically Threaded Stronghold Screwnail: Thread Spacing 0.034"	Helically Threaded Stronghold Screwnail: Thread Spacing 0.045"
		Inches	Pounds	Percent	Percent	Percent	Percent	Percent	Percent
Withdrawal Resistance	Directly	0.80	110	+98	+114	+103	------	------	------
		0.91	139	+45	------	------	+47	+57	+53
	Through Gyp. Bd.	0.91	209	+33	+ 20	+ 33	------	------	------
		0.86	173	+53	------	------	+43	+59	+57
Lateral Load-Carrying Capacity	Directly	0.80	201	+40	+ 39	+ 49	------	------	------
		0.91	245	+25	------	------	+ 5	+24	+14

Table VIII

Average Effectiveness in Resistance to Axial Withdrawal of 2-1/2" x 0.113" Plain-Shank Flooring Brads, 2-1/2" x 0.115" Tapered, Flat Cut Flooring Nails, and 2-1/2" x 0.113" Threaded-Shank Flooring Nails in Side-Grain Air-Dry Southern Pine

Driven Into Southern Pine Plank After	Tested after Given Delay	Plain-Shank Flooring Brad	Cut Flooring Nail	Helically Threaded Screwtite Flooring Nail
		Pounds	Percent	Percent
1-Week Soaking and 1-Day Air-Drying	None	211	+148	+214
1-Week Soaking and 1-Day Air-Drying	4-Week (12.5% M.C.)	165	+161	+259
Air-Drying (11% M.C.)	None (11% M.C.)	234	+156	+214
Air-Drying (11% M.C.)	4-Week (11% M.C.)	211	+169	+221
	Grand Average	100%	+158	+227

Table IX

Average Axial-Withdrawal Resistance of Plain-Shank and Threaded-Shank Nails in Side-Grain Air-Dry White Fir

Nail Group	Nail Metal	Nail Size	Plain-Shank Nail Pounds	Helically Threaded Screw-tite Nail Percent	Annularly Threaded Strong-hold Nail Percent	Helically Threaded Strong-hold Screwnail Percent	Cut Nail Percent
General-Purpose	L.-C. Steel	2-1/2" x 0.135"	260	+ 10	+ 72	----	----
"	H.H.-C. Steel	2-1/2" x 0.120"	266	+ 73	+ 73	----	----
"	L.-C. Steel	3" x 0.148"	299	+ 10	+110	----	----
"	H.H.-C. Steel	3" x 0.135"	447	+ 32	+ 25	----	----
Asphalt-Roofing	Aluminum-Alloy	1" x 0.120"	51	+ 39	+122	----	----
Shingle, Shake, Siding	Aluminum-Alloy	1-3/4" x 0.098"	86	+ 78	+126	+120	----
Lath	Blued L.-C. Steel	1-1/8" x 0.091"	85	----	+ 52	----	----
Wallboard	Aluminum-Alloy	1-3/8" x 0.091"	81	----	+ 73	+ 62	----
Flooring	L.-C. Steel	2-1/2" x 0.113"	114	----	----	----	----
"	H.-C. Steel	2-1/2" x 0.115"	---	----	----	----	+185
"	H.H.-C. Steel	2-1/2" x 0.113"	---	+266	----	----	----

Table X

Comparative Axial-Withdrawal Resistance of Plain-Shank and Threaded-Shank Nails in Side-Grain Air-Dry White Fir and Southern Pine

Nail Group	Nail Type	Nail Metal	Nail Size	In White Fir Pounds	In Southern Pine Pounds	Percent
General-Purpose	Screwtite	L.-C. Steel	2-1/2" x 0.135"	285	346	+ 21
	"	H.H.-C. Steel	2-1/2" x 0.120"	461	850	+ 84
	"	L.-C. Steel	3" x 0.148"	319	455	+ 43
	Avg.					+ 49
	Stronghold	L.-C. Steel	2-1/2" x 0.135"	447	652	+ 46
	"	H.H.-C. Steel	2-1/2" x 0.120"	461	730	+ 58
	"	L.-C. Steel	3" x 0.148"	604	934	+ 54
	Avg.					+ 53
Asphalt-Roofing	Plain-Shank	Aluminum-Alloy	1" x 0.120"	51	102	+100
	Screwtite	"	"	71	139	+ 96
	Stronghold	"	"	113	164	+ 45
	Gr. Avg.					+ 80
Shingle, Shake, & Siding	Plain-Shank	Aluminum-Alloy	1-3/4" x 0.098"	86	132	+ 53
	Stronghold	"	"	201	292	+ 45
	Strongh. Screwn.	"	"	196	307	+ 57
	Gr. Avg.					+ 52
Lath	Plain-Shank	Blued L.-C. Steel	1-1/8" x 0.091"	85	140	+ 65
	Stronghold	"	"	129	198	+ 53
	Gr. Avg.	"				+ 59
Wallboard	Plain-Shank	Aluminum-Alloy	1-3/8" x 0.091"	81	139	+ 72
	Stronghold	"	"	140	202	+ 44
	Strongh. Screwn.	"	"	131	218	+ 66
	Gr. Avg.					+ 61
Flooring	Plain-Shank	L.-C. Steel	2-1/2" x 0.113"	114	251	+120
	Cut	H.-C. Steel	2-1/2" x 0.115"	325	574	+ 77
	Screwtite	H.H.-C. Steel	2-1/2" x 0.113"	417	800	+ 92
	Gr. Avg.					+ 96

Table XI

Averages for Matched Quintuplicate Tests on Axial-Withdrawal Resistance for Two-Third Shank Penetrations and Per Inch of Shank Penetration and on Lateral Load-Carrying Capacity of Nails and Wood Screws in Air-Dry Southern Yellow Pine, White Oak, and Beech

Property	Wood Species	Nail Size	Plain-Shank Nail	Etched Pl.-S. Nail	Helically Threaded Screw-tite Nail	Annularly Threaded Strong-Hold Nail	Screw Size	Wood Screw
Withdrawal Resistance For 2/3 Shank Penetration In Pounds	SYP	2½" x 0.135"	317	423	346	652	5 - ¾" x 0.125"	317
							6 - 1" x 0.138"	501
		3" x 0.148"	---	---	455	934	7 - 1¼" x 0.151"	613
		4" x 0.203"	---	---	820	1443	8 - 2" x 0.164"	735
	White Oak	2½" x 0.135"	399	563	665	730	5 - ¾" x 0.125"	224
							6 - 1" x 0.138"	365
		3" x 0.148"	---	---	931	971	7 - 1¼" x 0.151"	613
		4" x 0.203"	---	---	1596	1593	8 - 2" x 0.164"	916
	Beech	2½" x 0.135"	563	627	705	773	5 - ¾" x 0.125"	267
							6 - 1" x 0.138"	407
		3" x 0.148"	---	---	987	1024	7 - 1¼" x 0.151"	619
		4" x 0.203"	---	---	1639	1613	8 - 2" x 0.164"	789
Withdrawal Resistance Per Inch Of Shank Penetration In Pounds	SYP	2½" x 0.135"	191	255	208	393	5 - ¾" x 0.125"	634
							6 - 1" x 0.138"	762
		3" x 0.148"	---	---	228	467	7 - 1¼" x 0.151"	613
		4" x 0.203"	---	---	352	619	8 - 2" x 0.164"	553
	White Oak	2½" x 0.135"	301	339	401	440	5 - ¾" x 0.125"	448
							6 - 1" x 0.138"	553
		3" x 0.148"	---	---	466	486	7 - 1¼" x 0.151"	613
		4" x 0.203"	---	---	685	664	8 - 2" x 0.164"	689
	Beech	2½" x 0.135"	339	378	425	466	5 - ¾" x 0.125"	534
							6 - 1" x 0.138"	617
		3" x 0.148"	---	---	494	513	7 - 1¼" x 0.151"	619
		4" x 0.203"	---	---	703	692	8 - 2" x 0.164"	593
Lateral Load-Carrying Capacity For 2/3 Shank Penetration In Pounds	SYP	2½" x 0.135"	627	732	813	829	5 - ¾" x 0.125"	283
							6 - 1" x 0.138"	341
		3" x 0.148"	---	---	881	924	7 - 1¼" x 0.151"	562
		4" x 0.203"	---	---	1728	1632	8 - 2" x 0.164"	582
	White Oak	2½" x 0.135"	787	793	861	911	5 - ¾" x 0.125"	264
							6 - 1" x 0.138"	385
		3" x 0.148"	---	---	965	1007	7 - 1¼" x 0.151"	588
		4" x 0.203"	---	---	1768	1671	8 - 2" x 0.164"	707
	Beech	2½" x 0.135"	784	848	827	883	5 - ¾" x 0.125"	255
							6 - 1" x 0.138"	365
		3" x 0.148"	---	---	951	966	7 - 1¼" x 0.151"	547
		4" x 0.203"	---	---	1836	1909	8 - 2" x 0.164"	844

membership campaigns, at and between Section meetings. They are also to advise and make suggestions to the Executive Secretary and Board on Society membership policies.

Effective membership campaigns have been conducted during the year and more are in the process of execution at this time. The spirit and enthusiasm of the committee is excellent and we are all convinced that much good will result from our activities.

Respectfully submitted, K. G. Chesley, *Chairman.*

8. Report of the Subject Matter Committee

In response to numerous requests the President set up an Executive Board committee on Subject-Matter Committees. The recommendations of this Committee were approved, and as a result, two Subject Matter Committees were set up since the last meeting. These are one on Education with R. W. Wellwood as Chairman, and one on Wood Drying with J. B. Welch as Chairman. The Committee on Education has been active and has participated in this meeting by arranging Session VI, "Training Men for the Wood Industries". The Committee on Wood Drying, set up in February 1951, has operated by correspondence since then. A third committee on Glues and Gluing and a fourth on Packaging are in the process of formation.

The duties of these committees in their respective fields are to:

1. Provide advice and guidance to officers and members of the Society on technical aspects relating to conducting the affairs of the Society.

2. Assist program committees by suggesting speakers and topics, and by otherwise aiding in the development of technical programs.

3. Sponsor and encourage meetings of experts for informal discussions of progress, methods, and problems.

4. Forward the objectives of the Society by coordinating the activities of members of the Society interested in the subject by formulating plans of action and otherwise encouraging activity in their technical fields.

Respectfully submitted, R. A. Hertzler, *Chairman.*

9. Report of the Resolutions Committee

The 1951 Committee on Resolutions offers the following resolutions for consideration of the Society.

1. In recognition that the success of this Fifth Annual Meeting of the Society is in a large measure due to the foresight, planning, and diligence of the various responsible committees, and in particular of the Philadelphia Meeting Committees.

Be it resolved that the Society hereby acknowledges its appreciation to the members of these committees for their excellent and successful work.

2. In recognition and appreciation of the excellent cooperation of the following cooperating organizations:

American Wood-Preservers' Association
American Society of Mechanical Engineers
American Society of Testing Materials
Northeastern Wood Utilization Council
Society of American Foresters
Society of Plastics Industry

Be is resolved that the Society hereby acknowledges its appreciation to these cooperating organizations for their efforts in making this meeting a success. Further that the Secretary so write these various organizations.

3. In appreciation of the meritorious services they have rendered the Forest Products Research Society during their period in office.

Be it resolved that the gratitude of the Society be extended to all of our outgoing officers and Regional and Sectional Board members.

4. The Society records with deep regret the passing away during the last year of the following members:

L. S. Black	Ross N. Perkins
P. A. Bloomer	R. H. Rawson
L. V. Frisch	G. A. Wagner
C. E. Miller	L. W. Winsor

A moment of silent prayer was observed.

5. In deep appreciation of the hospitality and courtesies extended by the City of Philadelphia and the State of Pennsylvania,

Be it resolved that this expression of gratitude to Governor Fine and Mayor Samuel be forwarded to each by the Society's Secretary and also be entered on the permanent records of the Society.

6. Whereas in the case of extreme national emergency the skills of all technically trained men should be utilized to the utmost, and whereas, the wood working industry has a large number of technically trained men,

Be it resolved that the Forest Products Research Society through the National Office of the Secretary recommend and send this resolution to the Secretary of Defense that men who are graduates of either Forestry or Engineering schools and who have had training in the wood working industry have their enlistment records so classified and where such men are already in the service they be reclassified that they may be identified in the particular branch of the service in which they are placed so that if it be necessary to form a special Wood Technologist Group in any of the various branches of the Defense Department these men may be so assigned.

Resolutions Committee, J. J. Allegretti, C. H. Jeter, J. R. Barnes, Newell Norton, R. L. Hiller, *Chairman.*

10. Report of Constitution and Bylaws Committee

Chairman K. G. Chesley reviewed the work of his committee, dating back to the origins of the Society, to draft a workable Constitution. Following completion of its assignment, early in 1951, the committee placed its recommendations in the hands of an independent advisory committee, headed by George M. Hunt, for further examination and recommendation. This advisory committee sought the counsel of the various Section officers and submitted its recommendations for changes to the original committee. The resultant revised documents, incorporating a number of the principal changes recommended, were approved by the Executive Board and the Section Officers Counsel at Philadelphia. Chairman Chesley read the principal changes incorporated from the efforts of the advisory committee. On motion duly made and seconded, the Constitution and Bylaws were adopted.

It was also moved and seconded that when the documents are sent to the membership for ratification a statement of recommended changes of the advisory committee, indicating those accepted and not accepted, accompany the documents. Motion defeated.

Moved that a copy of the Resolution recommending adoption of the documents made at the Section Officers Council Meeting accompany the documents. Carried.

11. New Business

No new business was presented.

President Hamilton acknowledged and thanked the members of the regional and national nominating committees. He also expressed his appreciation to retiring board members Clarence Van Epps and R. D. Pauley, to the entire executive board and the various committees of the 1951 meeting for their work.

12. Report of Tellers Committee

As the result of balloting for officers and board members for the year 1951 the following were declared elected:

President: Roy M. Carter, Raleigh, N. C.

First Vice-President: Kenneth G. Chesley, Crossett, Ark.

Second Vice-President: R. D. Pauley, Longview, Wash.

Northwest Regional Board Member, 3 year term: Fred Armbruster, Seattle, Wash.

Northeast Regional Board Member, 3 year term: W. Burdette Wilkins, Ridgewood, N. J.

Attested by the Tellers Committee, Herford Garland, Jack Hammond, Roswell D. Carpenter, *Chairman.*

13. Installation of Officers

Newly-elected President Carter expressed his appreciation to retiring president Hamilton, and to the membership for their confidence in the new Board.

14. Adjournment

The meeting was adjourned at 10:30 p. m.

1951 FOREST PRODUCTS INDUSTRY SHOW

TWENTY-THREE HUNDRED wood industries men from the United States, Canada, and many foreign countries attended FPRS' largest industry show at Convention Hall, Philadelphia, May 7–11. Eighty exhibitors were distributed through three major areas—quiet, semi-noisy, and outdoor—of the vast Hall. They displayed a wide range of products, including quiet area exhibits of chemicals, adhesives, raw materials, instruments and services . . . heavy machinery exhibits, many in actual operation, showing the latest in woodworking machinery . . . and outdoor exhibits which included power saws, sawmill and woods equipment.

The big feature of the show was the large amount of equipment in actual operation, coordinated with motors, drives, dust collection systems and auxiliary processing machinery. Here, a variety of secondary wood products rolled off continuous production lines.

The major theme of the exhibits was wood utilization, exemplified by such products as wood waste board, new binders, and machines offering better machining efficiencies, lower kerf losses. A unique exhibit was the world's smallest, scale model, operating sawmill.

Motion Picture Program

A new, and valuable addition to the industry show was the "Forest Products Industries Film Theater" program conducted during the show. Located in the middle hall of the show, the theater was open daily from 10 A.M. to 5 P.M. and was heavily attended throughout the week. Featured was a continuous, changing program of practical wood industry motion pictures. Subjects covered included: Furniture manufacturing, Raw materials, Housing construction, Logging, Lumber manufacturing, Millwork, Pulp and Paper, Plywood, Woodworking machinery and Research in the wood industries.

The official industry show, international in scope of exhibits, was open from 9:00 A.M. through 5:00 P.M. daily, Monday through Friday. Companies exhibiting are listed on the following pages.

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Atlanta, Ga.

Bakelite Company
New York, N. Y.

Borden Company, The
New York, N. Y.

Bucknam Saw Grinder Mfg. Co.
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Catalin Corp. of America
New York, N. Y.

Chevrolet Motor Division
Detroit, Mich.

Como, M. & T. Bjerke
Stockholm, Sweden

Cosgrove Publishing Company
Grand Rapids, Mich.

Delmhorst Instrument Co.
Boonton, New Jersey

Delta Power Tool Division
Rockwell Mfg. Co.
Milwaukee, Wisconsin

DeLuxe Saw & Tool Co.
Chicago, Ill.

DeWalt, Inc., Subsidiary American Machine & Foundry Co.
Lancaster, Pa.

Disston & Sons, Inc., Henry
Philadelphia, Pa.

Durez Plastics & Chemicals, Inc.
North Tonawanda, N. Y.

Econaway Manufacturing Company
Bellevue, Michigan

Ekstrom, Carlson & Co.
Rockford, Illiniois

Electronic Heating Corp.
Newton Highlands, Mass.

Flmendorf Research, Inc.
Chicago, Ill.

Enterprise Company, The
Columbiana, Ohio

Firth Sterling Steel & Carbide Corp.
McKeesport, Pa.

Forest Products Research Society
Madison, Wisconsin

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Rockford, Ill.

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Homelite Corp.
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I. E. L. Power Saws, Inc.
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Industrial Woodworking
Greenwich, Conn.

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Brewton, Ala.

Junior–Pro Products Co.
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Kellogg Appliances Co.
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Lemmon & Snoap
Grand Rapids, Mich.

The Lumberman
Seattle, Washington

Maas & Waldstein Co.
Newark, N. J.

Mall Tool Company
Chicago, Illinois

Masonite Corp.
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Rockford, Illinois

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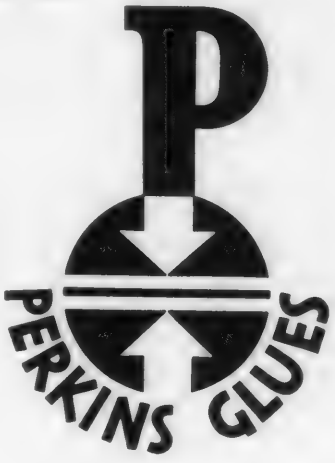
The Perkins Trade Mark is your guarantee of quality and reliability when you purchase glues. Since 1899, customer-confidence in Perkins has grown steadily—a deserved tribute to superior products backed by competent service and rigid ethical standards. When you use a Perkins Glue in your operations, you'll agree with other leading woodworkers—*that Perkins serves you best!*

GLUING PROBLEMS?

Dispose of them by calling upon the skilled assistance of the Perkins Technical Service Department. Specialists in gluing methods will study your particular operations and offer suggestions where pertinent. There is no cost or obligation involved in your use of this unbiased advice.

IT'S A PERKINS SERVICE!



RESIN—Hot Press and Cold Press • Liquid or Powder Type
CASEIN—A broad line to meet your specific requirement
VEGETABLE—As originated and perfected by Perkins Glue Co.
ANIMAL—Ready-to-use Liquid • Heat-then-use Gel

• • •

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ESTABLISHED 1899

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Alhambra, Calif.

Monsanto Chemical Co.
St. Louis, Mo.

National Casein Co.
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Northeastern Wood Utilization Council
New Haven, Conn.

Onsrud Machine Works, Inc.
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Perkins Glue Company
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Wood Magazine
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Woodworking Precision Machinery and Tool Co., Inc.
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Wood Working Digest
Wheaton, Illinois

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▼ Below: Stray field heating. ▶ Right: New 5 KW-6.8/13.6 MC dual frequency wood working generator.

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...for Profit!

Call on Westinghouse for profitable assistance with your gluing jobs. Radio Frequency gluing saves time and material and permits cost reductions. Westinghouse offers you:

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2. Engineering assistance. Westinghouse provides experienced engineering help on your particular wood gluing problem and is prepared to give you assistance, engineering-wise and cost-wise.

▲ Assembly gluing.

3. Field service. To protect your production operation, Westinghouse has field engineers in all principal cities to provide you with service and consulting facilities at all times.

Start your profits on the way up. Increase your shop capacity. Get the facts on how Westinghouse R.F. gluing can solve your gluing problems. Ask for Booklet B-3946-B, Radio Frequency Heating For The Wood Working Industry. Call your local representative or write Westinghouse Electric Corporation, Department FP, 2519 Wilkens Avenue, Baltimore 3, Maryland.

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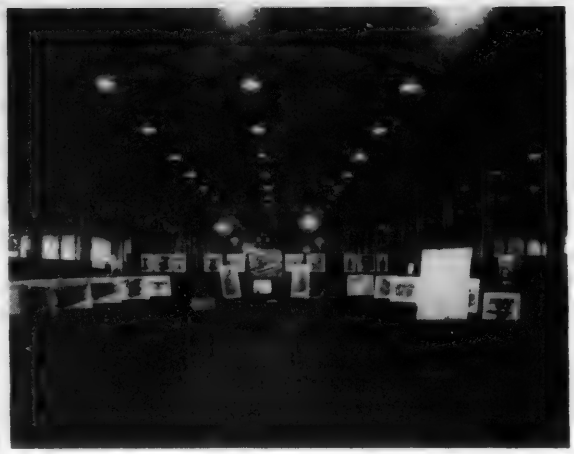
J-02210



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The Original WATER REPELLENT PRESERVATIVE

Containing PENTAchlorophenol

Protects **WOOD** *Against:*

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A clean penetrating *water repellent* preservative of the highest quality that stays in the wood. It resists leaching by moisture and retains maximum water repellent efficiency under adverse conditions. Used on structural lumber and millwork, cabinet work, sheathing, flooring, shipping containers, and many other wood items.

Protection Products Manufacturing Co.

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Join the "sidewalk superintendents" and you'll see what building gives America. On every hand, new construction . . . homes, factories, office buildings. Here's progress that's tangible . . . permanent . . . seeable. Progress that springs from brains, ingenuity, sweat — and chemicals.

Chemicals have many applications to building materials—add numerous improvements and economies. But, chemicals themselves are hard to see, since they are built into materials that are built into buildings. Their use extends from far below the ground line to far above it.

The useful life of dimension lumber and heavy structural timber, for example, is greatly increased by treating materials with Monsanto Penta preservative. The same applies to poles, millwork and insulating board.

Concrete forms, made of plywood, can be used over and over because of the extra strength of chemically formulated glues which meet all requirements of adhesion and resistance to exposure.

Many flooring materials offer greater resistance to abrasive wear when chemically treated—they last longer because they stand up better underfoot.

Plastics find wide use in wall coverings, switch plates, fluorescent fixture bodies and similar applications.

Pulverized wood is conserved by being chemically bonded and pressed into useful service.

In these, and numerous other ways, the benefits of chemistry accrue to owners, architects, engineers, contractors and manufacturers of building materials and supplies. They are benefits that go on and on, as buildings go up and up. MONSANTO CHEMICAL COMPANY, Organic Chemicals Division, 1700 S. Second Street, St. Louis 4, Missouri.

MONSANTO CHEMICALS—PLASTICS

MONSANTO PRODUCTS FOR THE BUILDING INDUSTRY — *Penta preservative for wood . . . Plywood glues . . . Rez, wood sealer and primer . . . White Rez, for bleached effects . . . Resinox* phenolic industrial resins . . . Resinox phenolic molding compounds . . . Resimene* melamine industrial resins . . . Resimene melamine molding compounds . . . Santocel,* flatting agent.* *Reg. U. S. Pat. Off.

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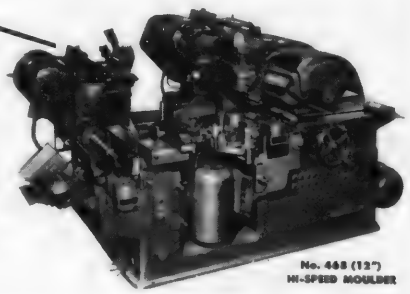
The constant aim and purpose of EKSTROM, CARLSON & CO. has been to design and build Machinery and Tools which will assist you in boosting your production and in reducing your manufacturing costs.



No. 448 (12") HI-SPEED MOULDER

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WOOD-LOK™ a proven production tool

REDUCES TOOL RE-SHARPENING COSTS

WOOD-LOK provides an easily machined wood bond

WOOD-LOK is a cold-run, liquid resin adhesive that sets to a non-abrasive film. Its glue film and squeeze-out do not calcify or dry to rock hard films that act as abrasives. WOOD-LOK will not dull saws and knives. It saves money by eliminating the high cost of re-sharpening tools unnecessarily; by making tools last longer because they dull less frequently; by decreasing the amount of lost production time usually needed to replace dull saws and knives on woodworking machinery.

WOOD-LOK is a proven tool that increases production. It was introduced six years ago to meet the demand for a really high-speed wood glue for joint assembly operations. It has since been scientifically improved to set 25% faster. Its quality and uniformity are rigidly maintained by laboratory controls over the materials and methods used in its production. For further information and samples, write:

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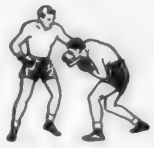
THE GREATEST CHAMPS REPEAT!



JOHN L. SULLIVAN

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There are hundreds of competitors in every field of sport, but only a few ever win the right to be called the greatest in history. Those are the ones whose *repeat* championship performances put them way out in front of all competition.

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Since 1887 Standard Dry Kilns have helped establish new high profit records in every conceivable kind of woodworking plant. Yes, and Standard is also setting another kind of record . . . a record number of repeat orders from men who have learned from profitable experience that they can depend on Standard's scientifically engineered kilns for the most efficient and economical performance. Remember this when it's time for you to install a new kiln or remodel an old one. And remember, too, that Standard's "CHAMP" internal fan construction and perfect automatic control of heat, humidity and ventilation is *your* assurance of uniform quality at lower operating cost.

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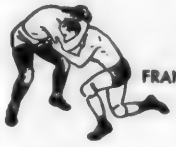

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DRY KILN COMPANY

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Take advantage of Greenlee's many years of practical, successful experience in building production woodworking machinery and tools. Greenlee's widely varied line can serve you in many profitable ways, whether your shop is large or small. Inquire now for further information that may eliminate costly operations in your production.

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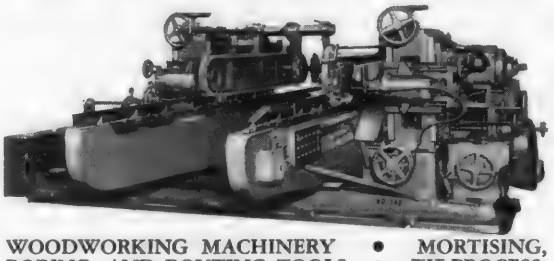

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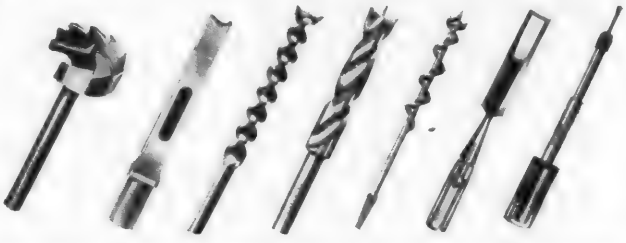

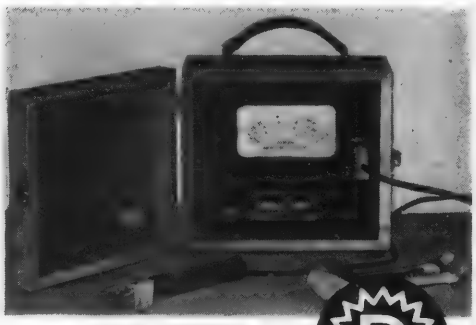

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DELMHORST MOISTURE DETECTORS measure moisture content of all kinds of wood over a range from 4 to 65%. Accurate readings read directly on the meter — no dials or knobs to turn — no calculations required.
Measures average moisture content and distribution of moisture.
Interchangeable electrodes to fit your needs — **Write for complete information on our various models for lumber, veneer, paper, etc.**

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. . . No man can do it—but an Auto-Nailer can, days on end. This great time-saver does the work of 3 to 5 men, driving 3 nails per second . . . straight, bradded, clinched or started. No guesswork either, for Auto-Nailer has quick, accurate settings for nail length and countersink.

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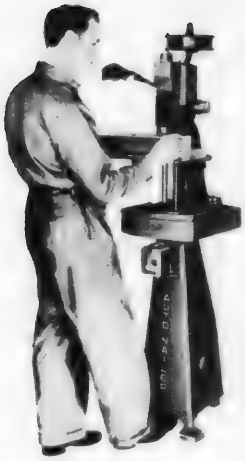

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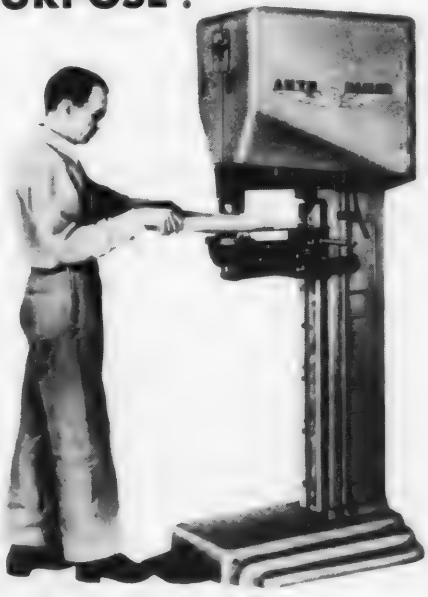

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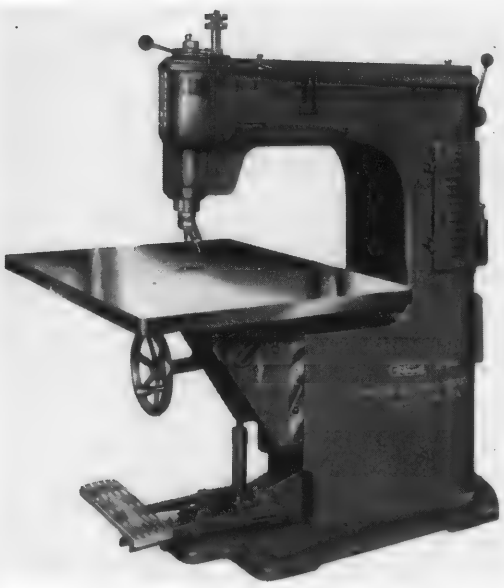

Onsrud *faster* machines for production woodworking

Onsrud machines today, for routing and shaping and related woodworking operations, give you greater speed and accuracy than ever before. Along with this you will have the advantages of easier operation and simplified maintenance. Typical of new-design Onsrud machines are the new W-244 and W-304 Heavy Duty Routers . . . and the new W-180 Medium Duty Router. Illustrated here is the W-304 Router. Design features include demountable and interchangeable spindle and vacuum pulley assembly . . . grease sealed super-precision bearings . . . table adjustable for height and tilt . . . and two spindle speeds, 10,000 RPM and 20,000 RPM set by simple hand lever control. Operating features include feather touch treadle control to raise and lower spindle and cutter to work, chip blower, and easy set-up to meet every work requirement. Write for the complete Onsrud Woodworking Machinery Catalog for information on all Onsrud machines, cutters and accessories.

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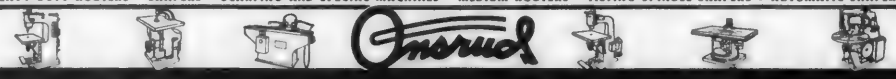

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PLASKON RESIN GLUES
FOR A DEPENDABLE GLUE LINE

The Plaskon Resin Glue line provides a choice of glues that are adaptable to a wide range of gluing and bonding needs for woods. These bonds have excellent strength and life, assuring a high degree of permanence. They are moisture-proof and resistant to bacteria and fungi. Other features include ease of preparation and handling, easy mixing and strong protection against splitting, cracking and peeling at glue lines.

Plaskon Resin Glues are available in hot and cold setting—powdered and liquid—for either low or high extension. All are of dependable quality and are stable in storage.

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PLASKON
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MOISTURE REGISTER

- Insures quality, tells moisture content for best woodworking results.
- Saves you money, helps cut freight costs.
- Protects your purchases, makes sure orders are filled correctly.
- Increases customer goodwill by insuring your deliveries to meet customer requirements.

Moisture Register Model RF4 with push-button electrodes.

Moisture Register instruments test moisture content in wood and wood products down to 0% with guaranteed performance. There's a model for every purpose, both radio frequency and needle types, priced for every budget. New models now available for wood waste and plaster. 10-day free trial offer. No obligation! Write today, outlining your requirements. Ask for information on Moisture Register instruments specially designed for the textile, leather, paper and wood industries.

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DRIVE STANDARD 12 GAUGE ROUND SASHPINS *AUTOMATICALLY!*

The dependable, production-tested Spotpinner automatically drives—and countersinks to suit—the familiar round 12 gauge sashpin to produce quality millwork at substantially lower cost.

The new Spotpinner has a double capacity magazine contained entirely within its virtually indestructible molded frame.

Spotpins are galvanized for rust resistance—knurled for better holding power—chiselpointed to avoid splitting check rails and muntins. Spotpins are round, straight (no offset) and cohered in sticks for quick magazine loading.

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Spotpins are made in standard 7/8", 1" and 1 1/8" sizes.

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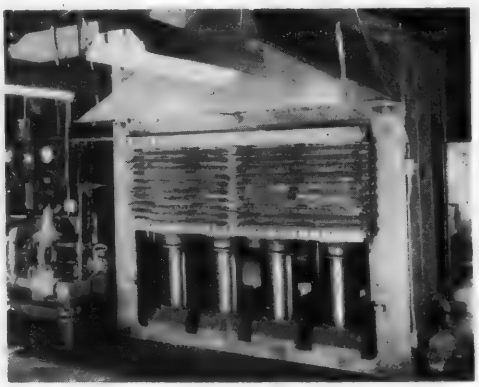

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STEEL FRAME HOT PRESSES

Here's the practical, efficient equipment for fast, economical production of plywood as well as for making board from wood fibre and wood waste. Solid one piece steel frames insure permanent alignment and even pressure. Available in a wide range of sizes from one to twenty openings.

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PLYCOR Electrogluer

Embodying the latest developments in high frequency edge-gluing, this unit insures finest quality at high speed and low cost. Fully automatic with conveyorized glue spreader.

Write for full details

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...if some of the properties of ordinary wood are unsatisfactory, perhaps we can help

BY chemical impregnation, the characteristics of wood can be radically changed. Resistance to decay, to marine borers, and to insect attack are widely recognized as qualities imparted by pressure treatment. Fire retardance may also be added to decay and termite resistance.

But there are many other ways in which wood can be made more useful.

Our Technical Laboratory has developed a variety of treatments for specialized needs. For example, wood can be treated so that it possesses one or more of the following valuable qualities: it resists acids; it is harder; it is dimensionally more stable; it absorbs less moisture, etc. With suitable treatment, wood stands up better under repeated steam sterilization, abrasive wear and other destructive conditions.

We will welcome an opportunity to consult and work with you to make wood serve you better.

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Koppers Company, Inc. Orrville, Ohio

PRESSURE-TREATED WOOD

PRESSED STEEL CAR COMPANY
Specifies SYNCO 128-CLW

FOR UNICEL FREIGHT CAR CONSTRUCTION. Even down to the massive yoke, Unicel Freight Cars are bonded with this versatile, low-cost phenolic resin that gives durable bonds in cold-press, hot-press, stored-heat and high frequency operations.

• SYNCO 128-CLW meets the following specifications:

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SYNCO RESINS AVAILABLE FOR
GLUING • LAMINATING
WOOD WASTE BONDING
BEATER ADDITION

SNYDER CHEMICAL CORPORATION
SYNCO RESINS
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A HELPING HAND

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Packaged Rough Dimension

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Core Stock
- Standard Lumber Cores
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Furniture Parts
- Rough
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Curved Laminates

Industrial Wood Parts

Turnings

Plastic-faced Material

for your production problems, whenever they arise: Gamble Brothers offers you, in effect, extended production facilities . . . increased volume, and greater versatility . . . without investment. By planning around the use of Gamble Brothers' hardwood dimension stock, or parts, either rough or finished, you can have the elasticity of production which is particularly important to economical operation today.

Gamble Brothers' helping hand reaches even farther. It places at your assistance more than fifty years of experience and know-how in wood engineering. Many have found this profitably helpful. Won't you, too, accept our hand?

GAMBLE BROTHERS GB GUARANTEED BOND

Engineered Wood Parts in Southern and Appalachian Hardwoods, Walnut or Mahogany.

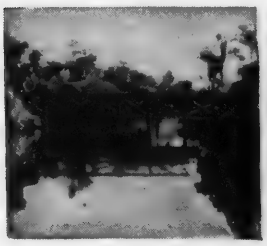
MAIN PLANT: LOUISVILLE 9, KENTUCKY BRANCH: MONTGOMERY, ALA.

WHEREVER YOU USE WOOD..

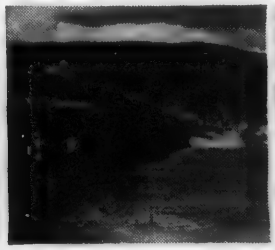
In the north, poles must resist the tremendous weight of frequent sleet storms. Barrett* Coal-Tar Creosote allows poles to retain their maximum strength, helps to keep the poles at their best.

In the south, high temperatures cause light-bodied preservatives to leach and evaporate from the wood rapidly. Barrett Coal-Tar Creosote, heavier bodied and of lower volatility, prevents this condition.

In the desert, crossties broom, shatter and split from extreme dryness and heat. Solutions made with Barrett Coal-Tar Creosote retard this, and reduce wear of crossties through their lubricating action on the wood fibers.



In the swamps, high moisture content and infection from other decaying wood are menaces. Poles properly treated with Barrett Coal-Tar Creosote survive under swamp conditions for years.



In fresh water, many preservatives leach out of wood. Coal-Tar Creosote, being only negligibly soluble in water, is the preferred preservative for use on submerged wood structures.

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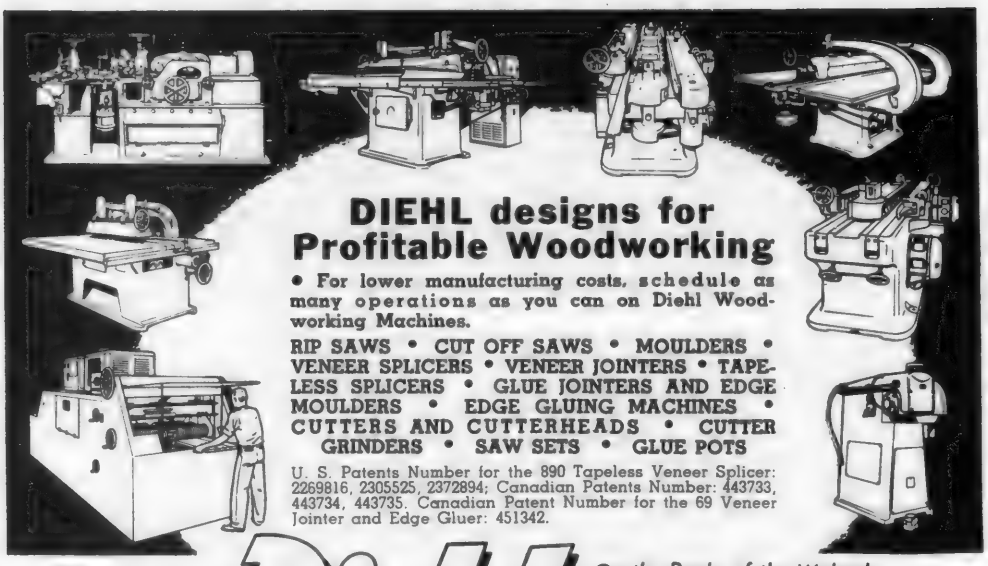
COAL TAR CREOSOTE



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U. S. Patents Number for the 890 Tapeless Veneer Splicer: 2269816, 2305525, 2372894; Canadian Patents Number: 443733, 443734, 443735. Canadian Patent Number for the 69 Veneer Jointer and Edge Gluer: 451342.

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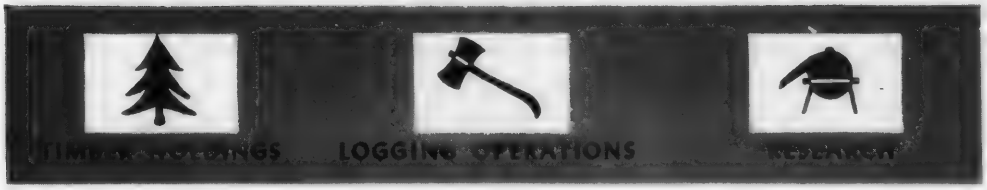

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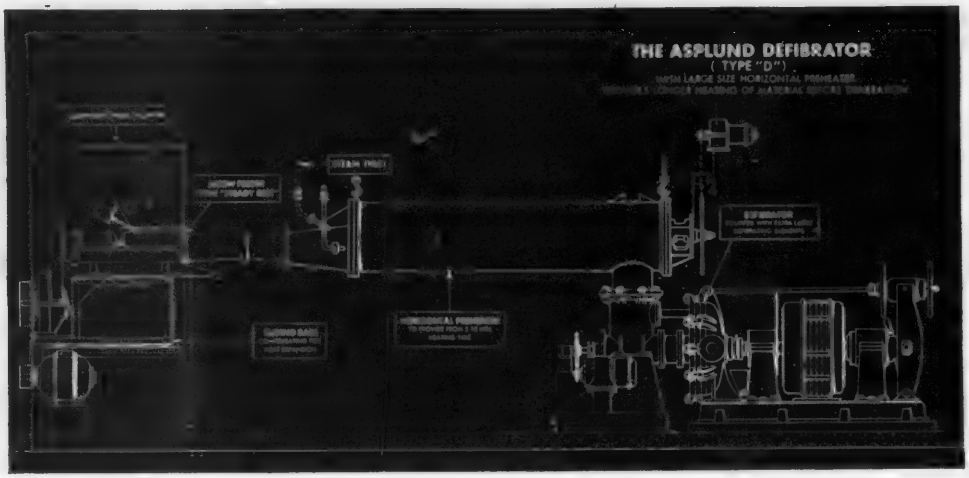

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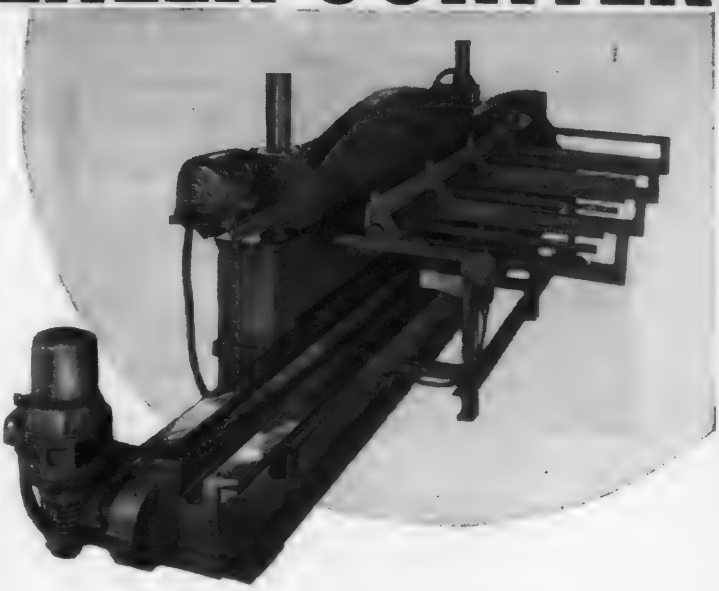

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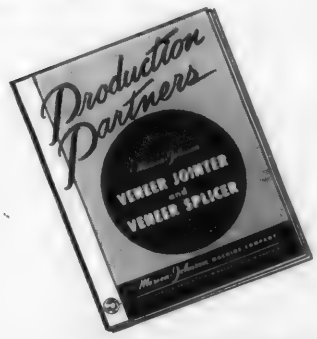

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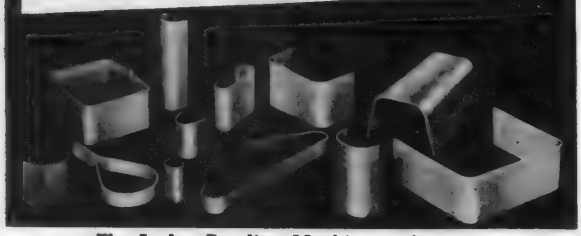
NEW *Ladon* Bending Machine Bends Wood Easily at Lower Cost



The Ladon Bending Machine makes reverse, close double, "S" shaped—any angle bend up to 180° —in plywood, veneers, hardboard such as Masonite, chipboard, Tekwood, metalfibre board laminates, etc.

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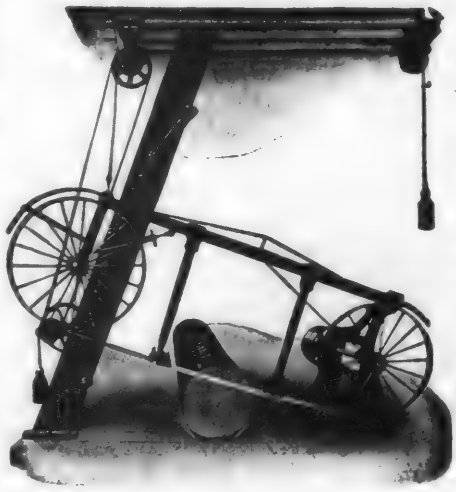

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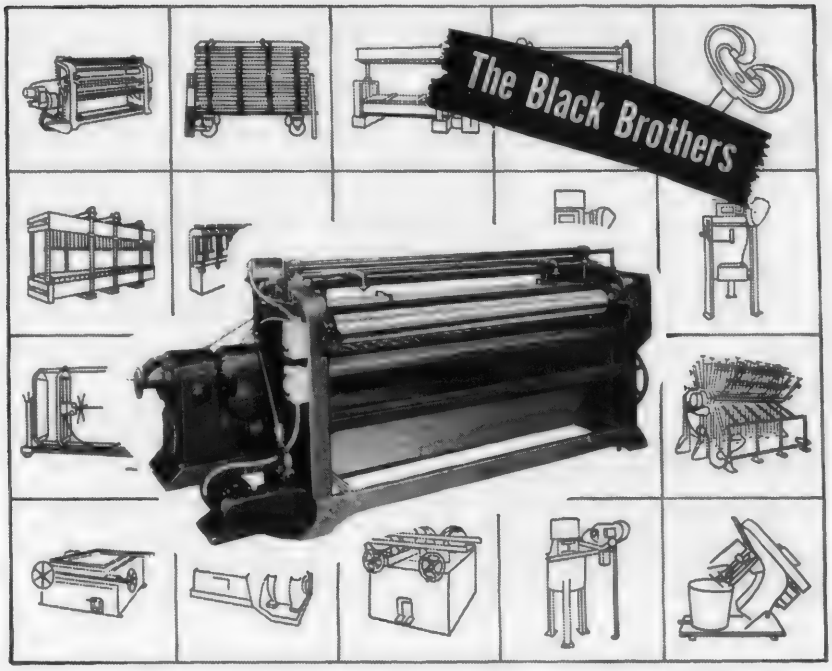

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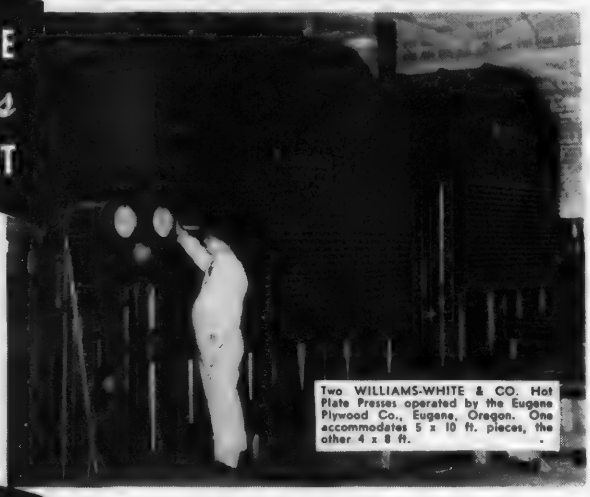

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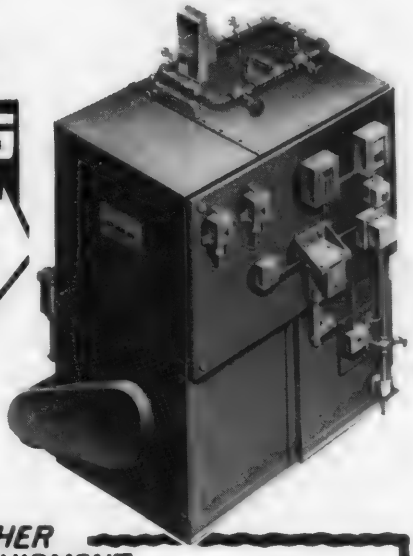

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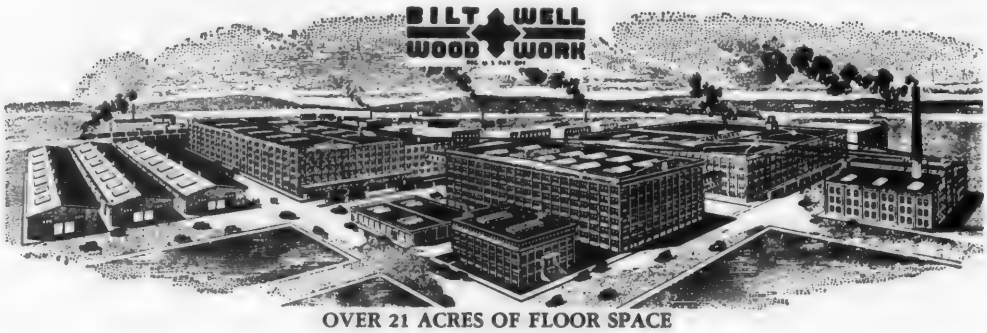

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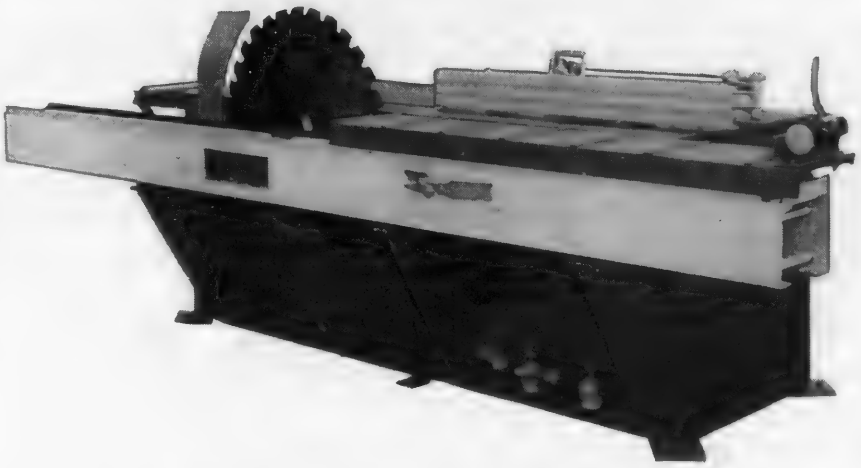

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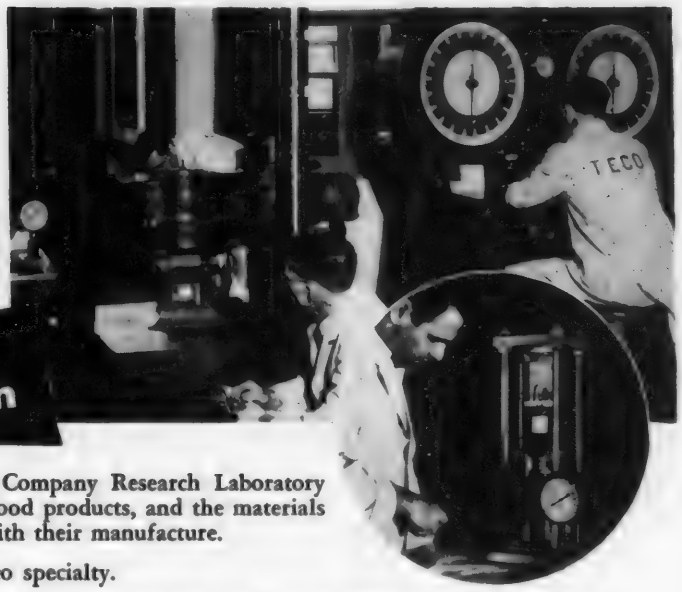

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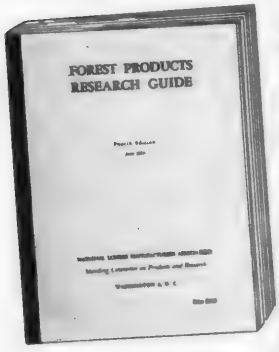

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"Famous the world over since 1904"

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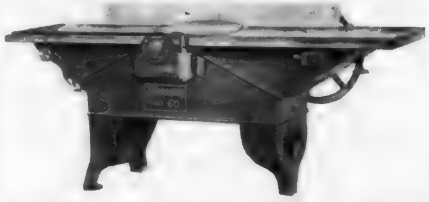
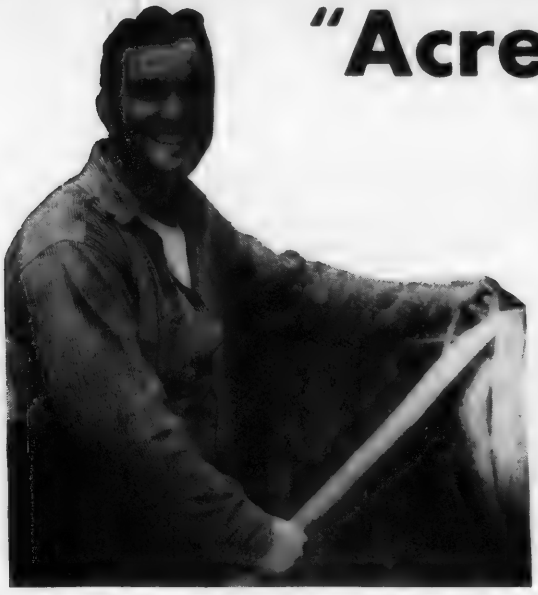
THE NEWMAN No. 60 HAND JOINTER



The Newman No. 60 Ball Bearing Hand Jointer is indispensable in any woodworking plant, large or small. For jointing and planing straight and out of line material, rabbetting, squaring, beveling, molding, beading, grooving etc., the No. 60 is unexcelled. Tables are 8 feet long adjusting laterally to give a maximum opening of 10" at cutterhead and a minimum opening of 1¾". Cylinder is forged from high carbon machine steel, accurately ground and dynetrically balanced and is mounted in Precision Type Ball Bearings. The Newman No. 60 can be adapted for high frequency operation, at any speed up to 7,200 R.P.M.

NEWMAN MACHINE COMPANY, INC.
GREENSBORO NORTH CAROLINA U. S. A.

"Acres of diamonds" Loggers' style



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Now days, he knows machinery;
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And BERGER is a name he trusts,
For job-proved engineering.

"Remember the world famous story? A man couldn't find riches anywhere—until he dug up 'acres of diamonds' in his own back yard.

"Today, the new 24-inch BERGER-REES AUTOMATIC AIR TONGS are bringing a new kind of conservation to the Northwest woods. It's spreading to Canada and you'll soon see it everywhere. Conservation that cleans up after logging!

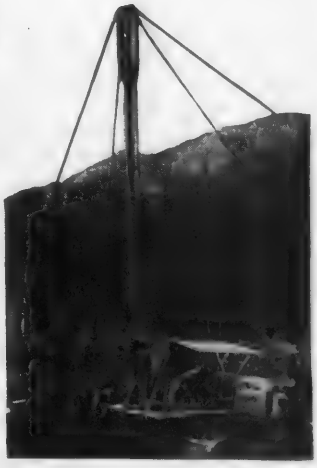
"Berger-Rees Automatic Air Tongs load small logs, chunks—material formerly wasted—economically and faster'n you can say Paul Bunyan.

"They're a surprise in another way, too—they add very little to your shovel investment. Small cost to open up 'acres of diamonds' with the

new 24-Inch BERGER-REES automatic AIR TONGS"

Also available: 50-inch, 42-inch, and 30-inch Air Tongs for sensational speed and efficiency in loading larger logs.

¾-yard Marion shovel loading varying length logs with 30-inch BERGER-REES Air Tongs.



Berger Portable Steel Logging Tower* with a truck-mounted Berger yarder. Highly mobile . . . ready-rigged . . . this successful combination brings high-lead efficiency to re-logging and pre-logging. Berger-Rees Air Tongs insure mobility throughout entire logging operation.

***N. W. loggers call it "the peanut post on the macaroni side."**

Inquire about Color Movies showing this revolutionary loading method in action on various kinds of logging shows.

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- ☐ **1. New 24-Inch Berger Automatic Air Tongs;**
- ☐ **2. Larger Size Berger Automatic Air Tongs.**

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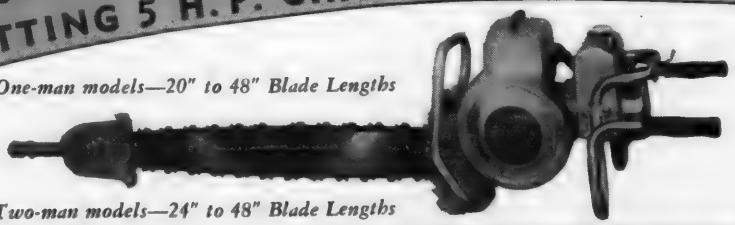

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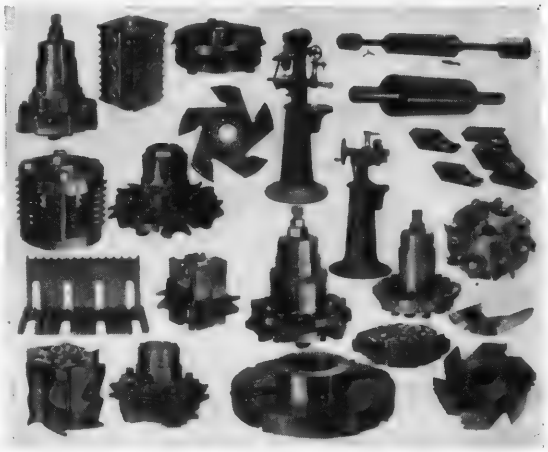

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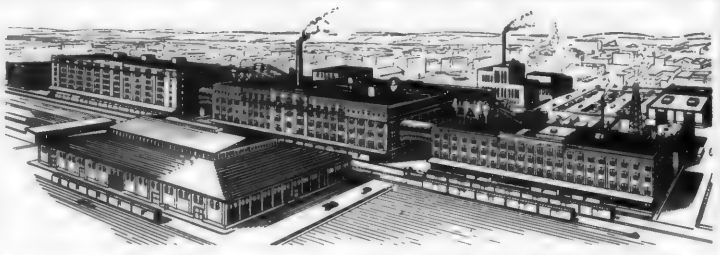

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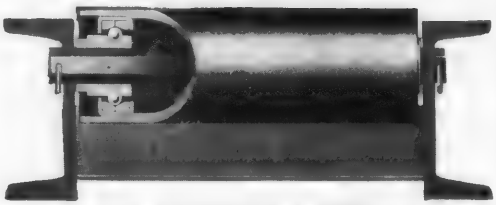

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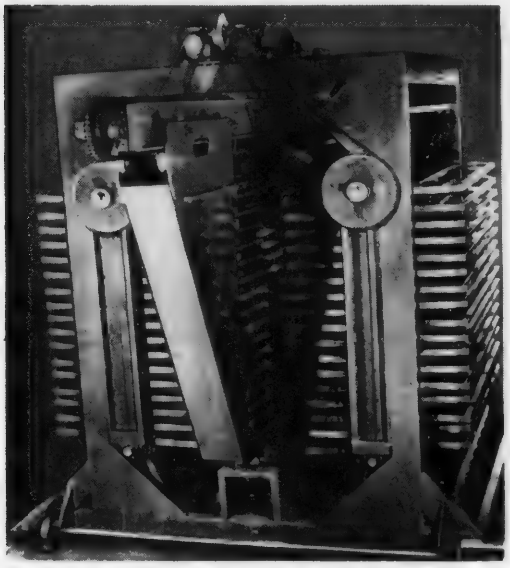

This Self-Elevating Charger is one of many units designed and built by American to provide maximum production.

As prime suppliers to Mill and Plywood Operators of Handling Equipment; Transfer Units; Sawing Equipment and numerous specially designed operations, we long ago saw the need for production machinery to handle wood waste.

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For On-the-Job Treatment of Lumber

CUPRINOL®

Applied by Brush, Spray or Dip

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Stops Rot and Termites

Reduces Warping and Swelling

Keeps Plywood Smoother

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CUPRINOL Supplements the Use of Pressure Treated Lumber

For Cuprinol permits on-the-job replacement of treatment after pressure treated lumber is fitted—on sawed ends, planed surfaces, in bolt holes, under fastenings, etc. And where a preservative is desirable but pressure treated lumber is unavailable, Cuprinol can be substituted.

Cuprinol is the original copper—or zinc—naphthenate wood preservative, first formulated in Denmark over 40 years ago. But in addition to its naphthenate base it contains other ingredients for deeper penetration, water repellency, quick drying and lasting protection.

It is Water Repellent, Fungus Resistant — Safe and Easy to Use

Primarily, Cuprinol treatment will stop rot, mildew and fungus accumulation, and deter termites and boring insects. But because Cuprinol is also water repellent it reduces the absorption of moisture by lumber so that fitted mill work, doors, windows, frames and flooring for all practical purposes will not swell, shrink or warp. On plywood this water repellency minimizes grain raising and separation checks to provide a lasting smoother surface under paint, varnish or stain.

Cuprinol does not leach out, and one coat is sufficient. It is non-toxic to the skin, and Cuprinol treated wood is harmless to animals, poultry and plants. Cuprinol treated wood takes paint perfectly, and Cuprinol is frequently used with economy to eliminate a priming coat. It does not deteriorate with the opening and closing of cans for frequent use, and is available in quarts, gallons, bulk or concentrates. Carried by Lumber Dealers. Write for Information Data WP-1.

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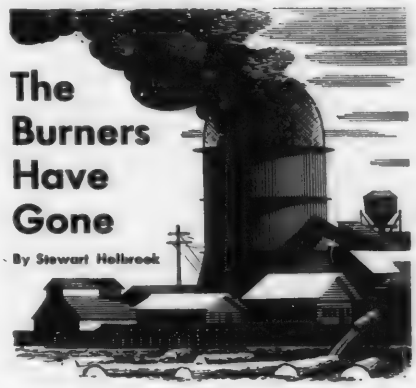

TIME OUT OF MIND, from coast to coast, from Lakes to Gulf, you could tell a sawmill by the hulking refuse burners. Their hot red eyes blinked through the night; by day they merely smoked. Burners were hard economic facts. They devoured what nobody would buy as lumber; and that which was left over from stoking the mill boilers.

I saw the light of Simpson's burner at its big Shelton, Washington, sawmills go out many years ago. The burner was a thing of the past when the company built its woodfiber plant, whose raw product, except for bark and inferior wood, is the very fuel that once fed the hot innards of the burner.

To make its woodfiber products, Simpson takes all the sound solid wood left over from the mills and factories, breaks it down into minute fibers, then feeds the pulpy mass into a machine. It emerges as a board, and goes next into a dryer as long as a football field. Now it is hard and firm again, and is cut into panels of any size desired. This insulating board can be used for interior walls, for lath to hold plaster, for wall sheathing and for roof insulation. In processing the product is treated to prevent rot and exclude termites.

Another Simpson woodfiber product is a sound-absorbing board called acoustical tile, its surface drilled with 484 holes to the square foot. Noises go howling into these little holes to emerge, if at all, as faint echoes.

The woodfiber plant added 250 new jobs to the community, and increased shipments of Simpson products by many hundreds of carloads annually. Yet all this was accomplished without having to cut a single extra tree. The identical stuff that kept the refuse burners smoking has become the source of new products.

Simpson
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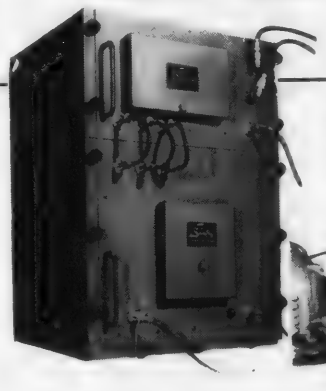
Laucks Sentry Moisture Detector Gives Continuous and Automatic Production-line Control Of Core Stock Moisture Content



Metal case control unit for overhead installation and probe unit to be permanently installed on production machine.

New Laucks Sentry Continuous Moisture Detector gives automatic, continuous production-line control of veneer or core stock moisture content—before assembly. This new instrument can be adapted to control moisture content of any material where moisture is a problem. It will detect moisture in any part of the material. You can set it to check any desired moisture content and arrange to mark automatically every piece of excessively wet stock, ring a bell or activate an automatic kick-off mechanism. It is built to meet rugged service requirements. Sentry is installed on present production equipment; operates at normal production speed; requires no special operators. It is installed by Laucks technicians who train present personnel in five hours.

Sentry has been use-tested for more than a year in a furniture plant where it paid for itself in six months. Other installations include additional furniture plants, veneer and pulp plants. An adaptation is being developed for use in connection with kiln dried lumber at large sawmills.

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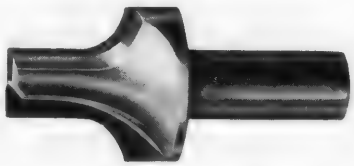

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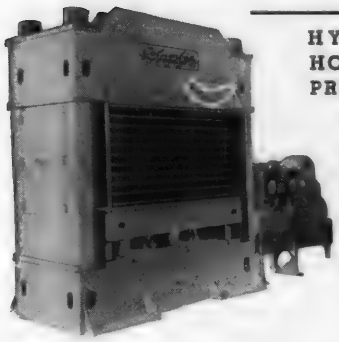

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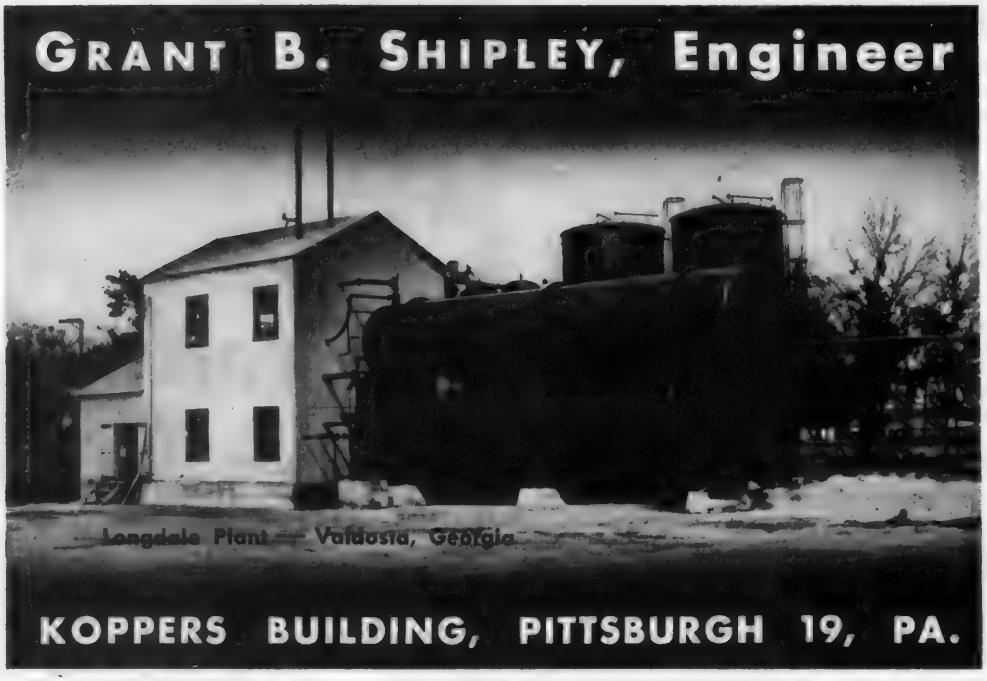

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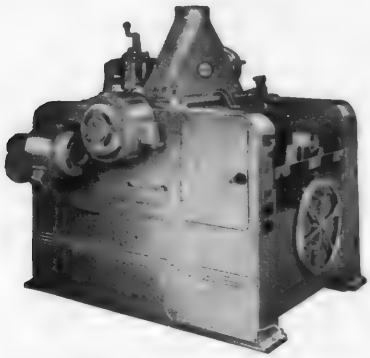

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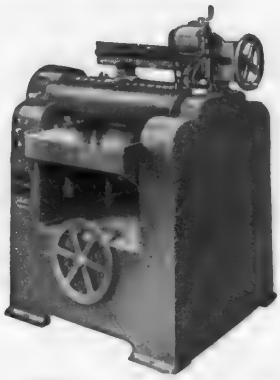

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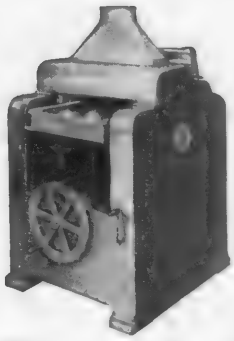

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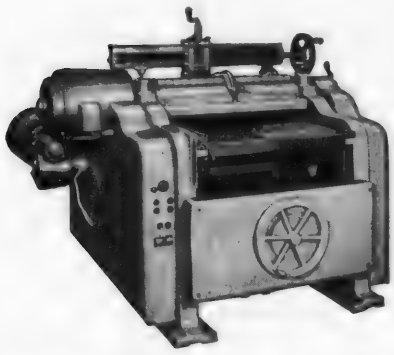

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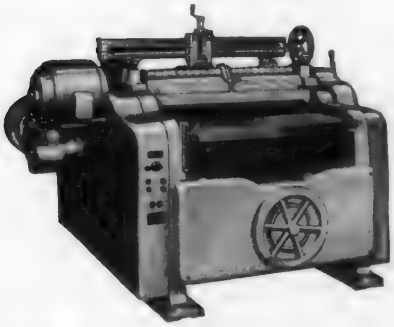

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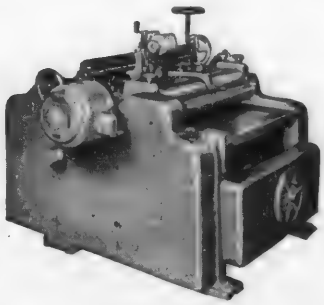

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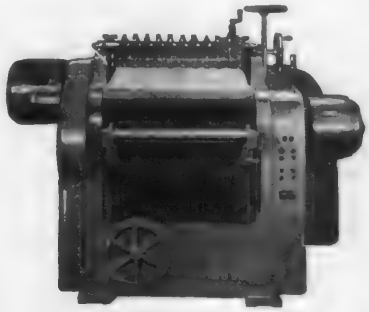

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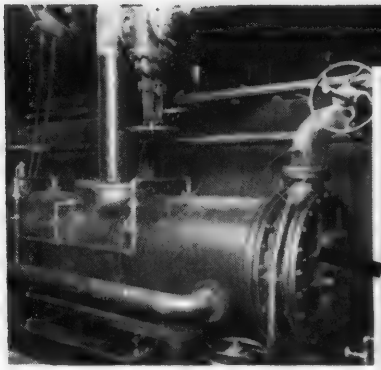

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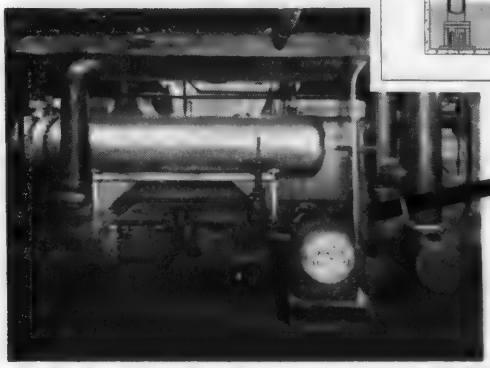

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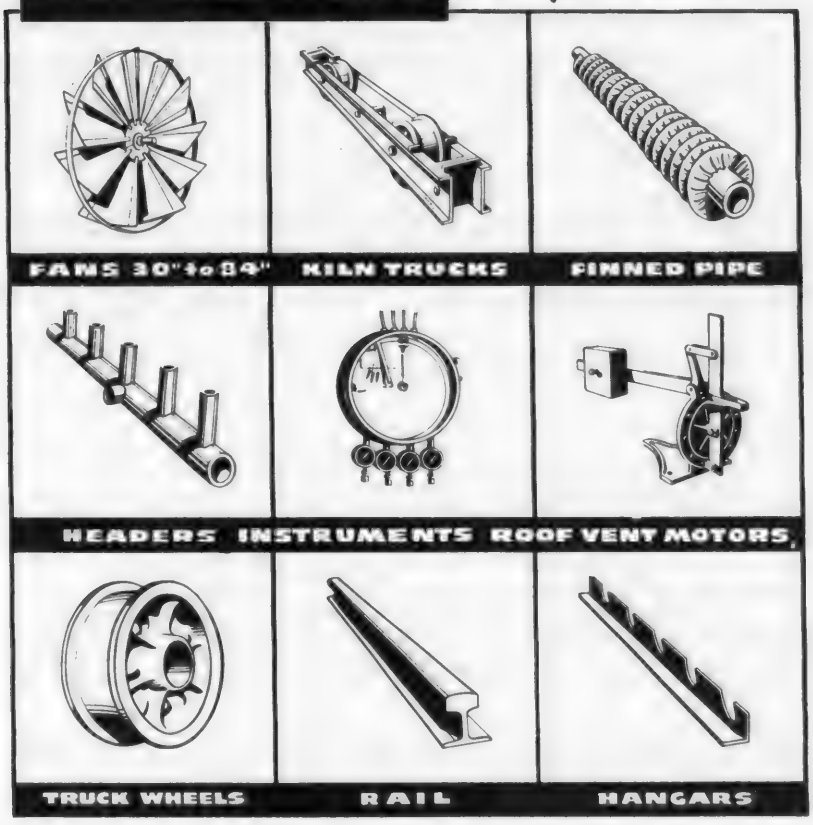

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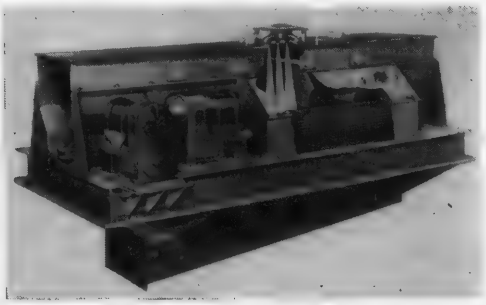

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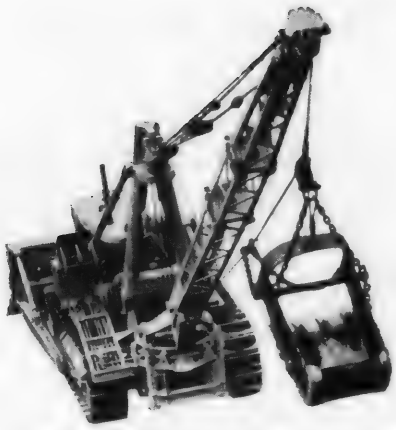

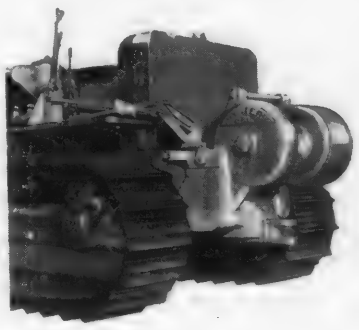

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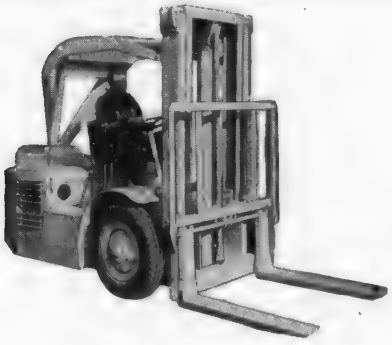

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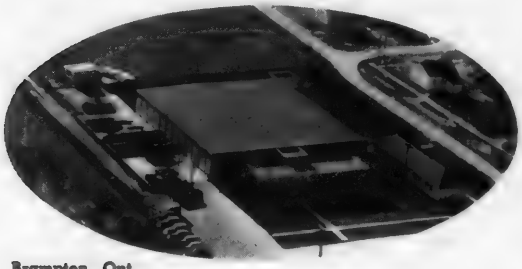

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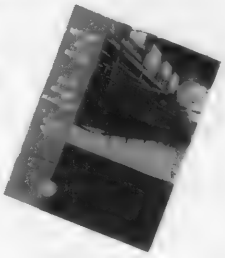

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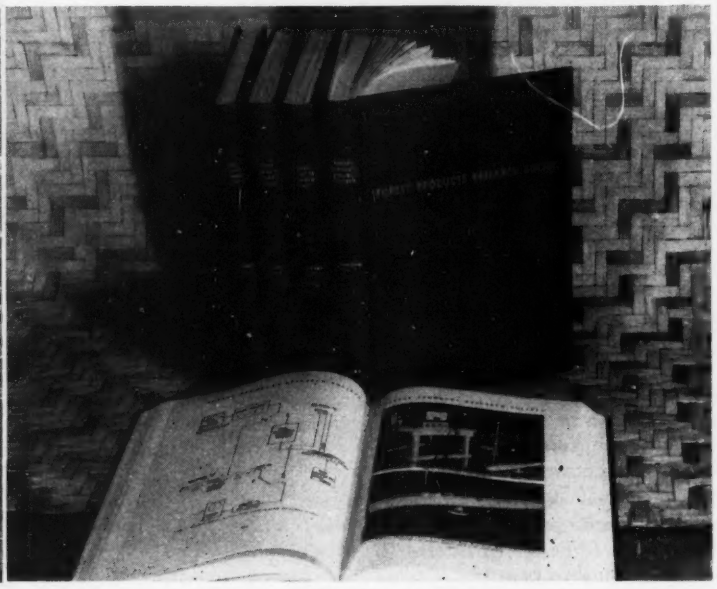

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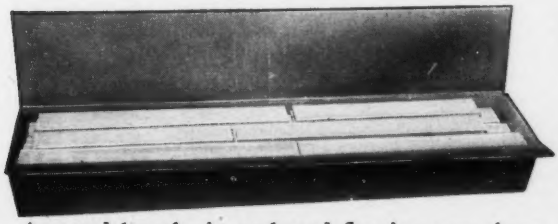

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Each carton is plainly marked for grade and scale—a definite aid to inventory.

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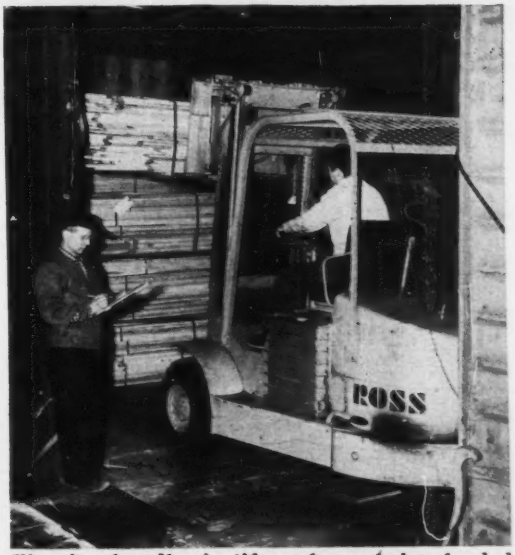
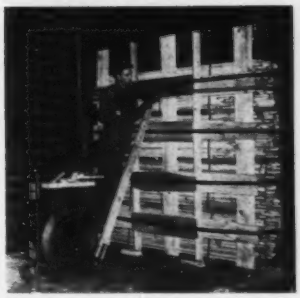


Flooring bundles in lift packages being loaded into a railway car by fork truck. Car can be unloaded in like manner, with fork truck entering car, in one-fourth the time required for manual handling or straps can be broken and car unloaded without a fork truck.



One end of car loaded with flooring in lift packages is being braced with steel strapping to prevent unit loads from shifting during transit from mill to dealer.

THE CONNOR LUMBER AND LAND CO.

P. O. Box 112-P **MARSHFIELD, WISCONSIN** **Telephone 3 or 418**

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